

## For Reference

---

NOT TO BE TAKEN FROM THIS ROOM

THE EFFECT OF HEAT TREATMENTS  
AND LOW TEMPERATURE UPON THE  
ELASTIC PROPERTIES OF METALLIC  
SINGLE CRYSTALS

by

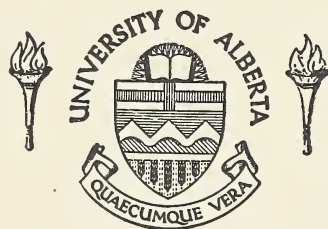
Martin C. Martin.

# For Reference

---

NOT TO BE TAKEN FROM THIS ROOM

Ex LIBRIS  
UNIVERSITATIS  
ALBERTAENSIS







THESIS  
1956 (F)  
#2D

THE UNIVERSITY OF ALBERTA

THE EFFECT OF HEAT TREATMENTS AND LOW TEMPERATURE  
UPON THE ELASTIC PROPERTIES OF METALLIC SINGLE CRYSTALS

A DISSERTATION

SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES  
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE  
OF DOCTOR OF PHILOSOPHY

FACULTY OF ARTS AND SCIENCE  
DEPARTMENT OF PHYSICS

by

MARTIN CLAUDE MARTIN

EDMONTON, ALBERTA,

1956



UNIVERSITY OF ALBERTA  
SCHOOL OF GRADUATE STUDIES

The undersigned hereby certify that they have read and recommend to the School of Graduate Studies for acceptance, a thesis entitled "The Effect of Heat Treatments and Low Temperature upon the Elastic Properties of Metallic Single Crystals" submitted by Martin Claude Martin in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

PROFESSOR

PROFESSOR

PROFESSOR

Date . August 24, 1956...



Digitized by the Internet Archive  
in 2018 with funding from  
University of Alberta Libraries

<https://archive.org/details/Martin1956>

## ABSTRACT

The effect of various heat treatments and low temperature upon the elastic moduli and elastic limits of beta-brass, copper, zinc, aluminum and magnesium single crystals was investigated. The experiment indicated that after heat treatments changes occurred in the elastic moduli or the elastic limit for all crystals. In some of the crystals both quantities showed an appreciable change after heat treatment. The beta-brass in both the ordered and disordered state showed an anomalous Young's modulus temperature variation. The copper crystal after being annealed at 500° C showed both an anomalous Young's and torsion modulus temperature variation. The elastic limit was found to be considerably greater at liquid nitrogen temperature for all the crystals with the exception of the torsion elastic limit of aluminum, and appeared to be affected by change in temperature to a greater extent than the elastic moduli.



## ACKNOWLEDGMENTS

The writer gratefully acknowledges the help and guidance given to him by Dr. H. Grayson-Smith, Head of the Physics Department, University of Alberta, under whose direction this study was conducted.

He wishes to thank Mr. F. Gleave and Mr. J. Kuziemyky for help in the construction of the apparatus used in the research.

His appreciation is extended to all those in the physics department to whom he has gone for advice.

The research was made possible, in part, by a grant from the National Research Council. The writer wishes to express his thanks to the Council for this assistance.



## TABLE OF CONTENTS

	Page
LIST OF TABLES . . . . .	i
LIST OF FIGURES . . . . .	vi
Chapter	
I    INTRODUCTION . . . . .	1
II   THEORY . . . . .	10
III  APPARATUS . . . . .	14
IV   EXPERIMENTAL PROCEDURE AND RESULTS . .	18
V    DISCUSSION OF RESULTS . . . . .	109
BIBLIOGRAPHY . . . . .	113
APPENDIX . . . . .	115



# LIST OF TABLES

Table		Page
I	Diameters and Lengths of Crystals . . . . .	20
	Load and Change in Length of the Crystals for the Young's Modulus Experiment	
I	Brass Crystal as Received. Temperature 24.0°C	22
II	Brass Crystal Annealed at 500°C. Temperature 28.1°C . . . . .	24
III	Brass Crystal Annealed at 500°C. Liquid Nitrogen Temperature . . . . .	26
IV	Brass Crystal Heated at 500°C and Quenched. Temperature 22.5°C . . . . .	27
V	Brass Crystal Heated at 500°C and Quenched. Liquid Nitrogen Temperature . . . . .	29
VI	Brass Crystal Annealed at 500°C and Quenched from 450°C. Temperature 22.1°C . . . . .	31
VII	Brass Crystal Annealed at 500°C and Quenched from 450°C. Liquid Nitrogen Temperature .	33
VIII	Brass Crystal Annealed at 500°C and Quenched from 400°C. Temperature 22.4°C . . . . .	35
IX	Brass Crystal Annealed at 500°C and Quenched from 400°C. Liquid Nitrogen Temperature .	37
X	Brass Crystal Heated at 575°C and Quenched. Temperature 22.4°C . . . . .	40
XI	Brass Crystal Heated at 575°C and Quenched. Liquid Nitrogen Temperature . . . . .	42
XII	Copper Crystal as Received. Temperature 27.9°C	43
XIII	Copper Crystal Annealed at 195°C. Temperature 28.1°C . . . . .	44



Table		Page
XIV	Copper Crystal Annealed at 195°C. Liquid	
	Nitrogen Temperature . . . . .	45
XV	Copper Crystal Annealed at 500°C.	
	Temperature 22.5°C . . . . .	46
XVI	Copper Crystal Annealed at 500°C. Liquid	
	Nitrogen Temperature . . . . .	48
XVII	Zinc Crystal as Received. Temperature 28.1°C	51
XVIII	Zinc Crystal Annealed at 100°C.	
	Temperature 25.0°C . . . . .	52
XIX	Zinc Crystal Annealed at 100°C. Liquid	
	Nitrogen Temperature . . . . .	53
XX	Aluminum Crystal as Received.	
	Temperature 21.8°C . . . . .	54
XXI	Aluminum Crystal as Received. Liquid	
	Nitrogen Temperature . . . . .	55
XXII	Aluminum Crystal Annealed at 200°C.	
	Temperature 22.5°C . . . . .	57
XXIII	Aluminum Crystal Annealed at 200°C. Liquid	
	Nitrogen Temperature . . . . .	59
XXIV	Magnesium Crystal as Received.	
	Temperature 21.6°C . . . . .	61
XXV	Magnesium Crystal as Received. Liquid	
	Nitrogen Temperature . . . . .	63
XXVI	Magnesium Crystal Annealed at 200°C.	
	Temperature 25.0°C . . . . .	65
XXVII	Magnesium Crystal Annealed at 200°C. Liquid	
	Nitrogen Temperature . . . . .	67
	Torque and Angle of Twist of the Crystals for the Torsion Modulus Experiment	
XXVIII	Brass Crystal Annealed at 500°C.	
	Temperature 25.4°C . . . . .	69



Table		Page
XXIX	Brass Crystal Annealed at 500°C. Liquid Nitrogen Temperature . . . . .	71
XXX	Brass Crystal, Heated at 500°C and Quenched. Liquid Nitrogen Temperature . . . . .	73
XXXI	Brass Crystal Annealed at 500°C and Quenched from 450°C. Temperature 22.0°C . . . . .	75
XXXII	Brass Crystal Annealed at 500°C and Quenched from 450°C. Liquid Nitrogen Temperature .	76
XXXIII	Brass Crystal Annealed at 500°C and Quenched from 400°C. Temperature 22.8°C . . . . .	78
XXXIV	Brass Crystal Annealed at 500°C and Quenched from 400°C. Liquid Nitrogen Temperature .	80
XXXV	Brass Crystal Heated at 575°C and Quenched. Temperature 22.4°C . . . . .	82
XXXVI	Brass Crystal Heated at 575°C and Quenched. Liquid Nitrogen Temperature . . . . .	84
XXXVII	Copper Crystal Annealed at 195°C. Temperature 23.8°C . . . . .	85
XXXVIII	Copper Crystal Annealed at 195°C. Liquid Nitrogen Temperature . . . . .	86
XXXIX	Copper Crystal Annealed at 500°C. Temperature 21.6°C . . . . .	87
XL	Copper Crystal Annealed at 500°C. Liquid Nitrogen Temperature . . . . .	89
XLI	Aluminum Crystal as Received. Temperature 22.8°C . . . . .	91
XLII	Aluminum Crystal as Received. Liquid Nitrogen Temperature . . . . .	93
XLIII	Aluminum Crystal Annealed at 200°C. Temperature 23.4°C . . . . .	94
XLIV	Aluminum Crystal Annealed at 200°C. Liquid Nitrogen Temperature . . . . .	95



Table		Page
XLV	Magnesium Crystal as Received. Temperature 24.0°C . . . . .	97
XLVI	Magnesium Crystal as Received. Liquid Nitrogen Temperature . . . . .	98
XLVII	Magnesium Crystal Annealed at 200°C. Temperature 25.5°C . . . . .	100
XLVIII	Magnesium Crystal Annealed at 200°C. Liquid Nitrogen Temperature . . . . .	102
	Elastic Moduli and Elastic Limits of Crystals	
XLIX	Young's Modulus and Elastic Limit: Brass Crystal . . . . .	103
L	Young's Modulus and Elastic Limit: Copper Crystal , . . . .	103
LI	Young's Modulus and Elastic Limit: Zinc Crystal . . . . .	104
LII	Young's Modulus and Elastic Limit: Magnesium Crystal . . . . .	104
LIII	Young's Modulus and Elastic Limit: Aluminum Crystal . . . . .	104
LIV	Torsion Modulus and Elastic Limit: Brass Crystal . . . . .	105
LV	Torsion Modulus and Elastic Limit: Copper Crystal . . . . .	105
LVI	Torsion Modulus and Elastic Limit: Magnesium Crystal . . . . .	106
LVII	Torsion Modulus and Elastic Limit: Aluminum Crystal . . . . .	106



Table		Page
LVIII	Effect of Heat Treatment and Low Temperature on Young's Modulus (Y) and Elastic Limit . . . . .	107
LIX	Effect of Heat Treatment and Low Temperature on Torsion Modulus (n) and Elastic Limit . . . . .	108



# LIST OF FIGURES

Figure		Page
1a	Idealized Diagram for Extension versus Load of a Single Crystal . . . . .	9a
1	Apparatus Used for the Measurement of Young's Modulus . . . . .	16
2	Apparatus Used for the Measurement of Torsion Modulus . . . . .	17
	Graphs for the Young's Modulus Experiment	
I	Brass Crystal as Received. Temperature $24.0^{\circ}\text{C}$	23a
II	Brass Crystal Annealed at $500^{\circ}\text{C}$ . Temperature $28.1^{\circ}\text{C}$ . . . . .	25a
III	Brass Crystal Annealed at $500^{\circ}\text{C}$ . Liquid Nitrogen Temperature . . . . .	26a
IV	Brass Crystal Heated at $500^{\circ}\text{C}$ and Quenched. Temperature $22.5^{\circ}\text{C}$ . . . . .	28a
V	Brass Crystal Heated at $500^{\circ}\text{C}$ and Quenched. Liquid Nitrogen Temperature . . . . .	30a
VI	Brass Crystal Annealed at $500^{\circ}\text{C}$ and Quenched from $450^{\circ}\text{C}$ . Temperature $22.1^{\circ}\text{C}$ . . . . .	32a
VII	Brass Crystal Annealed at $500^{\circ}\text{C}$ and Quenched from $450^{\circ}\text{C}$ . Liquid Nitrogen Temperature .	34a
VIII	Brass Crystal Annealed at $500^{\circ}\text{C}$ and Quenched from $400^{\circ}\text{C}$ . Temperature $22.4^{\circ}\text{C}$ . . . . .	36a
IX	Brass Crystal Annealed at $500^{\circ}\text{C}$ and Quenched from $400^{\circ}\text{C}$ . Liquid Nitrogen Temperature .	39a
X	Brass Crystal Heated at $575^{\circ}\text{C}$ and Quenched. Temperature $22.4^{\circ}\text{C}$ . . . . .	41a
XI	Brass Crystal Heated at $575^{\circ}\text{C}$ and Quenched. Liquid Nitrogen Temperature . . . . .	42a
XII	Copper Crystal as Received. Temperature $27.9^{\circ}\text{C}$	43a



Figure		Page
XIII	Copper Crystal Annealed at 195°C.	
	Temperature 28.1°C . . . . .	44a
XIV	Copper Crystal Annealed at 195°C. Liquid	
	Nitrogen Temperature . . . . .	45a
XV	Copper Crystal Annealed at 500°C.	
	Temperature 22.5°C . . . . .	47a
XVI	Copper Crystal Annealed at 500°C. Liquid	
	Nitrogen Temperature . . . . .	50a
XVII	Zinc Crystal as Received. Temperature 28.1°C	51a
XVIII	Zinc Crystal Annealed at 100°C.	
	Temperature 25.0°C . . . . .	52a
XIX	Zinc Crystal Annealed at 100°C. Liquid	
	Nitrogen Temperature . . . . .	53a
XX	Aluminum Crystal as Received.	
	Temperature 21.8°C . . . . .	54a
XXI	Aluminum Crystal as Received. Liquid	
	Nitrogen Temperature . . . . .	56a
XXII	Aluminum Crystal Annealed at 200°C.	
	Temperature 22.5°C . . . . .	58a
XXIII	Aluminum Crystal Annealed at 200°C. Liquid	
	Nitrogen Temperature . . . . .	60a
XXIV	Magnesium Crystal as Received.	
	Temperature 21.6°C . . . . .	62a
XXV	Magnesium Crystal as Received. Liquid	
	Nitrogen Temperature . . . . .	64a
XXVI	Magnesium Crystal Annealed at 200°C.	
	Temperature 25.0°C . . . . .	66a
XXVII	Magnesium Crystal Annealed at 200°C.	
	Liquid Nitrogen Temperature . . . . .	68a



Figure	Graphs for the Torsion Modulus Experiment	Page
XXVIII	Brass Crystal Annealed at 500°C. Temperature 25.4°C . . . . .	70a
XXIX	Brass Crystal Annealed at 500°C. Liquid Nitrogen Temperature . . . . .	72a
XXX	Brass Crystal, Heated at 500°C and Quenched. Liquid Nitrogen Temperature . . . . .	74a
XXXI	Brass Crystal Annealed at 500°C and Quenched from 450°C. Temperature 22.0°C . . . . .	75a
XXXII	Brass Crystal Annealed at 500°C and Quenched from 450°C. Liquid Nitrogen Temperature .	77a
XXXIII	Brass Crystal Annealed at 500°C and Quenched from 400°C. Temperature 22.8°C . . . . .	79a
XXXIV	Brass Crystal Annealed at 500°C and Quenched from 400°C. Liquid Nitrogen Temperature .	81a
XXXV	Brass Crystal Heated at 575°C and Quenched. Temperature 22.4°C . . . . .	83a
XXXVI	Brass Crystal Heated at 575°C and Quenched. Liquid Nitrogen Temperature . . . . .	84a
XXXVII	Copper Crystal Annealed at 195°C at 23.8°C . .	85a
XXXVIII	Copper Crystal Annealed at 195°C. Liquid Nitrogen Temperature . . . . .	86a
XXXIX	Copper Crystal Annealed at 500°C. Temperature 21.6°C . . . . .	88a
XL	Copper Crystal Annealed at 500°C. Liquid Nitrogen Temperature . . . . .	90a
XLI	Aluminum Crystal as Received. Temperature 22.8°C . . . . .	92a
XLII	Aluminum Crystal as Received. Liquid Nitrogen Temperature . . . . .	93a
XLIII	Aluminum Crystal Annealed at 200°C. Temperature 23.4°C . . . . .	94a



Figure		Page
XLIV	Aluminum Crystal Annealed at 200°C. Liquid Nitrogen Temperature . . . . .	96a
XLV	Magnesium Crystal as Received. Temperature 24.0°C . . . . .	97a
XLVI	Magnesium Crystal as Received. Liquid Nitrogen Temperature . . . . .	99a
XLVII	Magnesium Crystal Annealed at 200°C. Temperature 25.5°C . . . . .	101a
XLVIII	Magnesium Crystal Annealed at 200°C. Liquid Nitrogen Temperature . . . . .	102a

# Appendix

i	Identification of a Crystal Axis from a Laue Photograph . . . . .	115
ii	Laue Photograph of Beta-Brass Single Crystal	116
iii	Determination of Angle of Tilt of Crystal Axis . . . . .	116a



## I INTRODUCTION

The broad purpose of the research was to investigate the effects of various heat treatments and of low temperature upon the elastic moduli and the elastic limits of beta-brass, copper, zinc, aluminum and magnesium in the form of single crystals. Although a number of investigations have been carried out on the elastic properties of single crystals, very little if anything has been done about the effect of heat treatments upon these properties.

The lattice structures of the crystals are as follows:

Copper	- face-centred cubic
Aluminum	- face-centred cubic
Zinc	- hexagonal close-packed
Magnesium	- hexagonal close-packed
Beta-brass	- body-centred cubic

All the crystals were obtained from Horizons Incorporated, in the form of rods about 6 inches long by about 1/8 inch diameter.

The structure of beta-brass exhibits a striking change in going from high to low temperatures. At temperatures above  $480^{\circ}\text{C}$  the crystal is disordered, with the cube-corner and body-centre positions of the unit cell occupied at random by either copper or zinc atoms. As the temperature is reduced through  $480^{\circ}\text{C}$ , it begins to pass into an ordered state, in which one set of positions <sup>is</sup> ~~are~~ occupied by copper atoms and the other by zinc. At low temperatures, therefore, the structure is better described as consisting of two interpenetrating simple cubic lattices, one of copper and the other of zinc. The transition is continuous with decrease of temperature, and is not complete until a temperature well below  $480^{\circ}\text{C}$  is reached. It is therefore classed as a transition of the second order, having no change in density or



latent heat, but only a maximum of the specific heat, at the transition point.

Research on the elastic properties of single crystals began around 1920. Since that time investigations on the behaviour of many single crystals under static or repeated stresses have been pursued. It seems appropriate to include here some of the research done in the past on the crystals used in the present work and the conclusions reached by the workers, since a number of the conclusions are relevant to the present work.

Of the five crystals investigated in this research, aluminum has been studied in the past to the greatest extent; and was one of the first single crystals to be investigated. However, most of the work concerns the manner of deformation when a crystal is distorted beyond its elastic limit, and the properties after extreme deformation. What research has been carried out on undistorted crystals has usually been incidental to study of the deformations, and very few of the investigations have been extended to low temperatures.

Taylor and Elam (1923) studied the distortion of an aluminum crystal during a tensile test. They observed that up to 40 percent elongation the distortion of the specimen was due to simple shear in one direction parallel to one of the crystal planes, and that the material preserved its crystal symmetry with the crystal axis practically unaltered throughout the extension.

Further research was carried out on aluminum single crystals by Gough, Hanson and Wright (1926). They investigated the behaviour of the crystals under static and repeated stresses and were able to draw the following general conclusions:

- (1) The crystals possessed no state of simple elasticity, plastic strain occurring under the lowest stresses applied.



- (2) The plastic strain consisted of a shear in the direction of a principal line of atoms in one or more of the octahedral planes of the crystal.
- (3) The first effect of slip in any plane was to increase its resistance to further slip. At the same time a similar hardening effect was produced in other planes.
- (4) Slip in any part of a specimen appeared to be confined to that octahedral plane along which the shear stress in one of the principal atomic directions was greatest.
- (5) The hardening effects appeared to be connected in some way with a permanent distortion of the crystal.

At about the same time as the work of Gough, Hanson and Wright other sets of experiments were performed on aluminum crystals by Karnop and Suchs (1927) and by Yamaguchi (1928). Karnop and Suchs showed that crystalline aluminum rods whose axes lay almost parallel to a crystal diagonal possessed, on the average, a resistance to stretching 10 to 15 percent greater than other aluminum crystals. They also showed that the firmness qualities of aluminum depend only to a small degree upon the speed of the deformation. Yamaguchi showed that at room and higher temperatures, the slip lines in aluminum are not perfectly straight, but present an irregular, segmented, wobbly form when viewed along the slip direction.

A recent experiment carried out on the slip in aluminum single crystals by Heidenreich and Shockley (1948) showed that what appears under an ordinary microscope to be a single slip line is revealed under the electron microscope to be a cluster of steps, each step being about 200 Angstroms



in height (measured normal to the slip plane) with a slip of about 2000 Angstroms per step. As deformation proceeds, the number of lamellae per cluster was observed to increase until adjacent clusters ran together producing one large cluster.

The most recent experiments on single crystals of aluminum have been investigations of the effect of temperature upon the elastic moduli and the critical shearing stress. Ting-Sui Kê (1949) obtained the shear modulus temperature coefficient for aluminum by measuring the modulus over the temperature range 0 to 500° C, and pointed out that the value of the coefficient is the same as that for polycrystalline aluminum at temperatures where the grain boundary relaxation does not occur. This indicated that the temperature variation of the shear moduli of aluminum along various crystallographic directions is similar.

Yamashita (1953) measured the values of the Young's modulus and elastic limit of the principal crystallographic axes for aluminum single crystals at temperatures 15° C, 100° C, 200° C and 300° C. He observed that the values of the Young's modulus and elastic limit decreased with rising temperature and that such a decreasing behaviour was different according to the crystallographic orientation. He also showed that the critical shearing stress decreases with increase in temperature.

An extended piece of research on aluminum single crystals was carried out by Cahn (1951). According to Cahn all the distorted crystals proved on examination to have slipped predominantly in the (111) plane and along the  $[110]$  direction. Furthermore, all specimens had marks of cross slip which took place in several distinct planes. The proportion of cross slip increased with the deformation and with rising temperature of deformation. Deformation bands were found

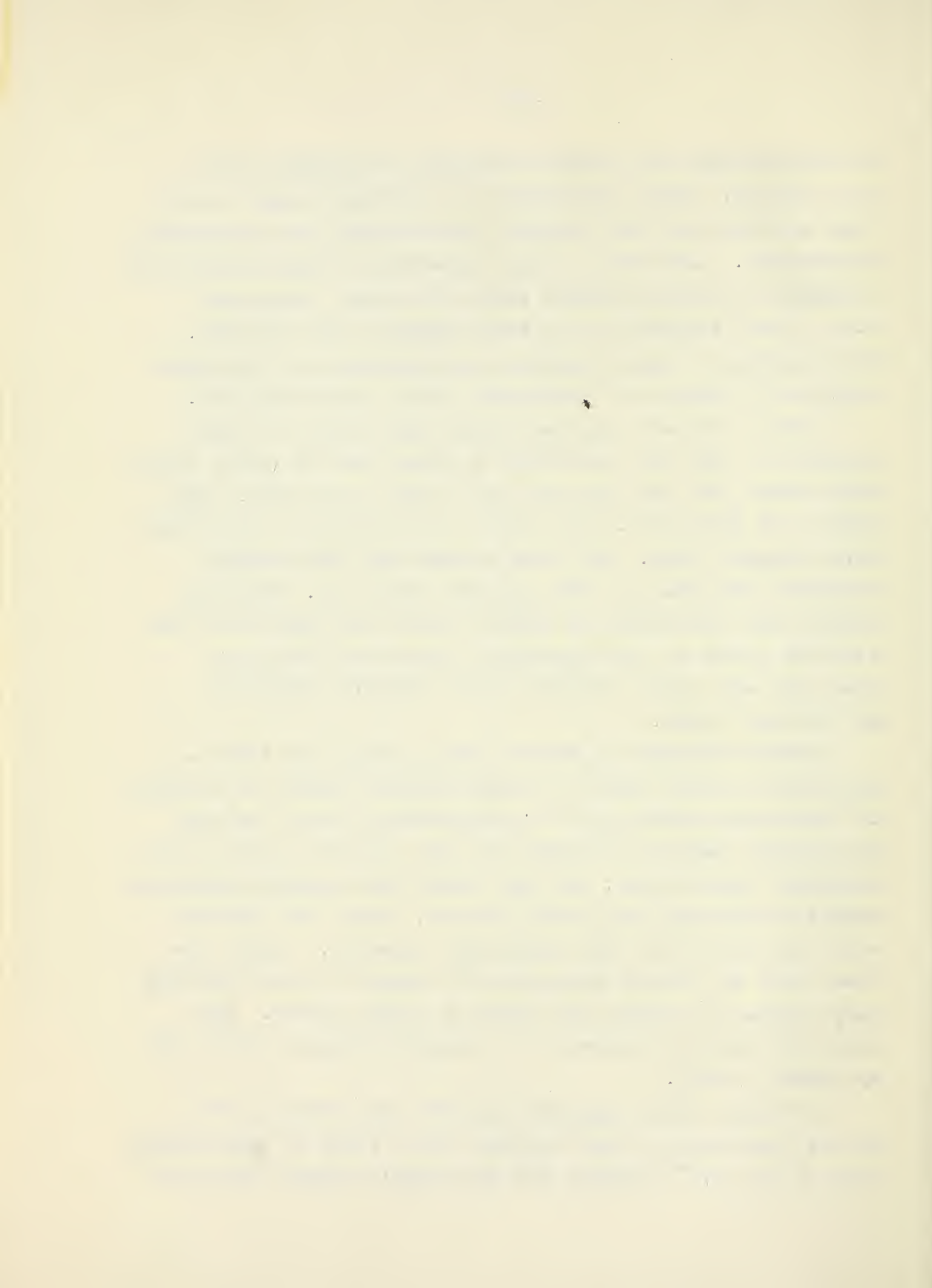


to be associated with uneven elongation of adjacent parts of a crystal. Their orientation was initially normal to the slip direction and then changed systematically with increasing deformation. Annealing at high temperatures caused progressive formation of closed polygons within the bands, associated with a local rumpling of the free surface of the specimen. The formation of these markings was accelerated by the application of a tensile or compressive stress while annealing.

One of the more important early experiments on single crystals of zinc was carried out by Gough and Cox (1929, 1930). They showed that the principal slip plane is the basal (001) plane, and that slip in this plane is restricted to one of the three diagonal axes. They also showed that the ultimate fracture took place in three general directions. They concluded that deformation by slip is controlled entirely by the resolved stress in the appropriate directions and occurs along the most highly stressed axial direction contained by the basal plane.

Further research by Hanson (1934) showed that there is a definitely limited range of proportionality between an initially increasing stress and the corresponding strain, and that the elastic range is a minimum for rods oriented at  $45^{\circ}$  to the hexagonal crystal axis. He also showed that elastic hysteresis occurs for bending but not for torsion, except for crystals which had previously been permanently strained. Hanson also found that the elastic properties of samples of zinc differing only slightly in purity may differ by large amounts. This last conclusion was proven to be wrong by Bridgman (1935) and by Tyndall (1935).

A fairly recent experiment by Wert and Tyndall (1949) on the elasticity of zinc crystals over a range of temperatures from  $0^{\circ}$  C to  $375^{\circ}$  C showed that the Young's modulus decreases



with increasing temperature for all orientations.

One of the first important experiments on the elasticity of copper single crystals was done by Elam (1926). He studied the structural change of the crystal under a tensile test, and observed that the position of the crystal axis remained practically unaltered throughout an extension which far exceeded the elastic limit. As the result of a comparison of aluminum and copper single crystals he concluded that although aluminum hardens slightly more rapidly than copper at first it finally becomes much weaker.

Göler and Sachs (1929) studied by X-rays the structural change of copper single crystals while under tension, and concluded that the deformation was due to a crystallographic gliding process.

Nowick (1950) investigated the variation of internal friction in single crystals of copper with frequency and temperature. He concluded that the internal friction and elastic modulus are independent of the strain frequency, but vary with temperature, and can be expressed as the product of a function of temperature and a function of amplitude alone when the crystal is subjected to an alternating stress.

Gaffney and Overton (1954) have recently measured the adiabatic elastic constants of oriented single crystals of copper from  $4.2^{\circ}$  A to  $300^{\circ}$  A. They found that at  $4.2^{\circ}$  A the values of  $C_{11}$ ,  $C_{12}$  and  $C_{44}$  were greater than those at room temperature by 4.8 percent, 2.8 percent and 8.6 percent respectively.

The effect of annealing copper single crystals was investigated by Neurath and Koeler (1951). They found that the yield stress was increased by annealing. The effect of the introduction of solute atoms into copper was investigated by French (1951). He found that both the plasticity and

the first of these is the fact that the  
the second is the fact that the  
the third is the fact that the  
the fourth is the fact that the  
the fifth is the fact that the  
the sixth is the fact that the  
the seventh is the fact that the  
the eighth is the fact that the  
the ninth is the fact that the  
the tenth is the fact that the

the eleventh is the fact that the  
the twelfth is the fact that the  
the thirteenth is the fact that the  
the fourteenth is the fact that the  
the fifteenth is the fact that the  
the sixteenth is the fact that the  
the seventeenth is the fact that the  
the eighteenth is the fact that the  
the nineteenth is the fact that the  
the twentieth is the fact that the  
the twenty-first is the fact that the  
the twenty-second is the fact that the  
the twenty-third is the fact that the  
the twenty-fourth is the fact that the  
the twenty-fifth is the fact that the  
the twenty-sixth is the fact that the  
the twenty-seventh is the fact that the  
the twenty-eighth is the fact that the  
the twenty-ninth is the fact that the  
the thirtieth is the fact that the

electrical conductivity of copper decreased as the concentration of solute atoms increased, and suggested that the dispersion of solute atoms in copper controls the flow of atoms in a uniform deformation in an analogous manner to its control of the mean free path of the electron.

The first work on the elasticity of single crystals of beta-brass was carried out by Taylor (1928). He found the crystals to be elastically anisotropic. Within a certain range of orientations of the crystal axis in the specimen, slip occurred in the (110) plane of the crystal, but in another range of orientation it did not occur in any definite crystallographic plane. He also pointed out that resistance to slip is least when the plane of slip coincides with a crystal plane of the type (110), and that the resistance to slipping in one direction on a given plane is not the same as the resistance to slipping in the opposite direction.

Elam (1936) in a more recent work suggested that the deformation does not take place by slip in any definite crystal plane, but that the distortion is brought about by movements of a complicated nature initially related to the structure, but finally having no connection with it.

Since the work of Taylor a number of workers (Webb 1939; Good 1941; Lazarus 1948; Artman and Thompson 1951, 1952) have measured the elastic moduli of beta-brass single crystals at room temperature. Their results are in fair agreement and all show that the Young's modulus is least in the [100] direction and greatest in the [111] direction, while the rigidity modulus is greatest in the [100] direction and least in the [111] direction.

Rinehart (1940, 1941) investigated the effect of temperature upon the Young's modulus of beta-brass single crystals.



He observed that in the  $[100]$  direction the Young's modulus increased with increase in temperature over the range  $-200^{\circ}$  to  $200^{\circ}$  C, and in the  $[110]$  direction for temperatures over the range  $-200^{\circ}$  to  $0^{\circ}$  C, contrary to the usual behaviour of elastic materials. A later investigation by Artman (1952) has confirmed the work of Rinehart.

Artman and Thompson (1952) investigated the effect of composition upon the Young's and rigidity modulus of beta-brass single crystals and found that both moduli were decreased by a small excess of copper.

Less work has been done on the elastic properties of magnesium single crystals than on the crystals previously mentioned. Schmid (1931), from X-ray studies of stretched magnesium single crystals at room temperature, concluded that slip occurs in the basal plane along the direction of the diagonal axis closest to the stress direction. This conclusion was based on experiments with crystals of many different orientations relative to the stress axis.

Bakarian and Mathewson (1943) made a study of slip in magnesium single crystals at room temperature and at  $330^{\circ}$  C and  $345^{\circ}$  C. They concluded that basal slip alone operates below  $225^{\circ}$  C, and that slip occurs in both the basal and the  $(101)$  planes at temperatures above  $225^{\circ}$  C. However, even well above  $225^{\circ}$  C the critical shearing stress for slip in the  $(101)$  plane was found to be six times that for basal slip.

Cahn (1949-50) investigated the recrystallization of single crystals of magnesium, zinc, aluminum and rock salt after plastic bending. He observed that these crystals when bent showed a special type of recrystallization which lead to discontinuous asterisms in their Laue patterns. The microstructures of bent and annealed specimens were also examined by Cahn. He found that the annealed specimens consisted of many crystallites



separated by straight boundaries perpendicular to the slip planes.

The experimental work to be described in this thesis has concerned the effect of various heat treatments and low temperature upon the elastic moduli and elastic limits of the previously mentioned single crystals. The effect of heat treatment was studied more extensively in beta-brass than in the other crystals because of the fact that this crystal becomes disordered above  $480^{\circ}\text{C}$ , as described previously. The beta-brass crystal, as well as being annealed at higher temperatures, was quenched from various temperatures above and below the critical temperature. If an alloy such as beta-brass exists at a high temperature in a structural form different from that which is stable at room temperature, then by cooling the alloy rapidly from a high temperature to room temperature, the structure characteristics of the high temperature may persist at room temperature. It is then in a non-equilibrium state, but if the activation energy is fairly high the rate of approach to equilibrium may be so slow that the quenched state is effectively stable, and the crystal is said to possess "frozen-in" disorder. Since the attainment of the ordered state in beta-brass involves exchange of atoms, it is extremely slow at room temperature. Thus, by studying quenched crystals, it is possible to compare the properties of the ordered and disordered states, at the same temperature.

Most single crystals show some evidence of plasticity over the low range of loading. Plasticity is a permanent slip that is proportional to the load for small loads, which may depend on the rate of loading as opposed to distortion beyond the elastic limit, which increases much faster than proportionality for large loads, up to the breaking point. Figure 1a is an idealized diagram for extension versus load of a single crystal. The elastic limit is taken as the stress corresponding to the point on the curve where it departs from a straight line, in spite of the fact that some plasticity occurs over the low range of loading.



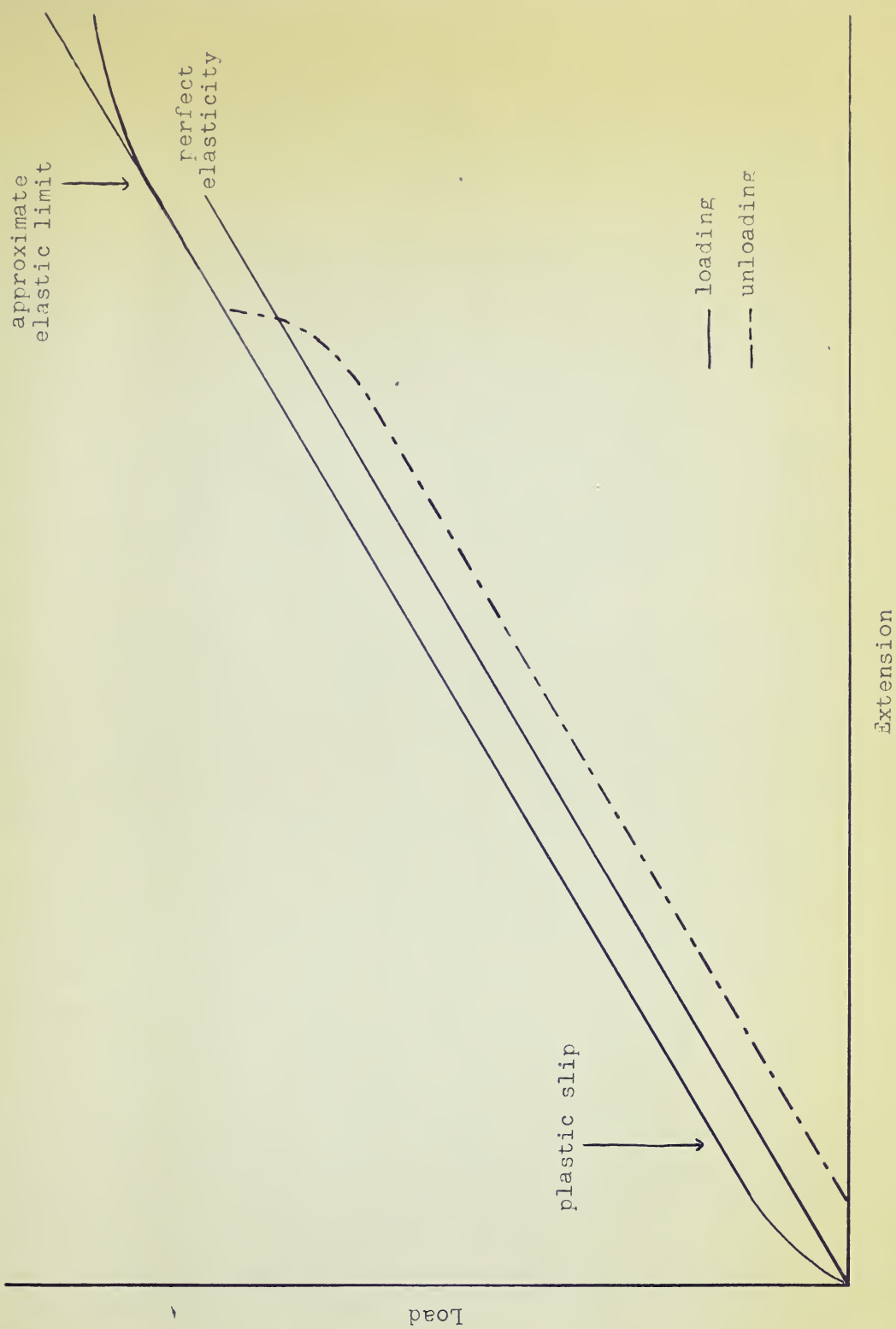


Fig. 1a. Idealized Diagram for Extension versus Load of a Single Crystal



## II THEORY

From the metallurgical point of view, great interest attaches to the determination of the cohesive forces in a metal binding the structure together. It is unfortunately not possible at present to relate the cohesive forces of a metal to its structure-sensitive mechanical properties. In a mechanical test, the elastic limit and tensile strength are reached long before the applied force becomes an appreciable fraction of the strength of cohesion, due to the fact that these properties are determined by abnormal conditions existing at irregularities in the structure.

If the energy of a metallic crystal can be calculated as a function of the lattice spacing, it becomes possible to determine such properties as the lattice constants, the compressibility and the coefficient of thermal expansion. By studying the change of energy with change in shape of the crystal cell, the elastic constants may be calculated.

Calculation of the crystal energy as a function of the interatomic spacing is, however, very difficult; for the nature of the problem is such that an exact mathematical treatment is impossible, and it is not easy to introduce simplifying approximations without losing the accuracy that is necessary to give the results quantitative significance. Only for certain metals does the problem become sufficiently simple to allow reliable calculations to be made by the methods available at present. Therefore, I will attempt only a brief and qualitative discussion of the theory of elastic properties of single crystals.

Single crystals have anisotropic elastic properties. Under applications of small ranges of loading, slipping occurs on certain planes in the crystal. This slip process causes



a plastic strain which is anisotropic in nature. Exact investigations of the slip process have shown that the process is not continuous in character but actually consists of a large number of small slip steps which are propagated throughout the crystal. In stretching experiments the slip plane approaches a position more and more parallel to the axis of the stress, which usually causes a change in the orientation of the crystal.

Large discrepancies exist between the actual and theoretical yield values of crystals. The actual values are of the order of 1000 to 10,000 times less than the theoretical force required to shift all the atoms in one slip plane with respect to the atoms in the adjoining slip plane. Several theories have been put forward to account for this characteristic feature of crystalline plasticity. Although differing widely in their details, they may be said to be based, in one way or another, on a common principle, namely that the presence of inhomogeneities of some kind (flaws for example) in a test piece prevents the applied exterior load from acting homogeneously over the full extent of the test piece, thus causing premature rupture as a consequence of stress-concentrating effects.

Of the various theories put forward in order to explain crystalline plasticity, one by Taylor (1934) appears to offer the best explanation. He conceived the process of slip as being brought about by the propagation through the lattice of a definite type of deviation called a dislocation. A dislocation is present, if along a certain length of a slipping plane, the row immediately above the plane contains one atom more or one atom less than the row immediately below the plane. When the atoms on one side of the slip plane are moved with respect to those on the other side, some of the atoms at the slip



plane will experience repulsive forces and others will experience attractive forces from their neighbours across the slip plane. To a first approximation these forces cancel, so that the external force required to move a dislocation will be quite small. If the dislocation line is not straight, the cancellation will be even more complete. Calculations show that dislocations in an otherwise perfect crystal can be made to move by very low stresses, probably below  $10^5$  dynes/cm<sup>2</sup>. Thus dislocations may make a crystal very plastic.

Taylor assumed that the distance over which a dislocation can be propagated is not given by the dimensions, but is limited by flaws. The dislocation upon reaching some irregularity in the crystal lattice, be it foreign atoms or a flaw, instead of being propagated in a regular manner, will produce a local distortion of the lattice which will be the seat of a system of stresses. As the deformed state of the crystal is thus characterized by the presence of an ever increasing number of arrested dislocations, an internal field of stress arises which may be expected to influence the further development of the slip process. Thus the stress necessary for the displacement of newly formed dislocations increases with the number of dislocations already arrested in flaws, that is with the deformation already attained. According to Taylor this explains the phenomenon of shear hardening, that is, the increase of yield stress with previous deformation which is almost always observed.

Finally the increase of plasticity with temperature which occurs in most crystals is explained by Taylor by assuming that the resistance which the flaws oppose to the passage of dislocations decreases with increasing temperature, as a consequence of the thermal agitation of the atoms. At higher temperatures the free path of a dislocation will thus be greater



than the mean spacing of the flaws, so that the number of dislocations which can be displaced by a given shear stress gives rise to a larger macroscopic shear.

As previously mentioned, beta-brass has shown an anomalous temperature variation of Young's modulus in the  $[100]$  and  $[110]$  directions at low temperatures. Only one attempt has been made to explain this anomaly. Zener (1947) attributed it to an anomaly in the temperature variation of the shear coefficient  $1/2(C_{11}-C_{12})$ , since this enters into the expressions for the Young's modulus in the  $[100]$  and  $[110]$  directions when the Young's modulus is put in terms of the bulk modulus and the shear coefficients. He attributes the change in sign of the temperature coefficient of  $1/2(C_{11}-C_{12})$  at higher temperatures to a decrease in the coefficient due to disordering.



### III APPARATUS

A photograph of the apparatus used for the Young's modulus measurements is shown in figure 1. It consisted of a heavy wooden structure as shown in the figure. Three stainless steel rods about 30 cm. long and 0.65 cm. in diameter were threaded into a heavy brass washer which was fastened below a hole of about 4 cm. diameter in the top of the wooden platform. A removable circular brass plate was fastened to the bottom of the stainless steel rods. The ends of the crystals in the form of rods about 15 cm. long and from about 0.3 to 0.5 cm. diameter were soldered with Wood's metal into brass sleeves of approximately 1.5 cm. length and 1.0 cm. diameter, threaded on the outside. Throughout the experiment there was no evidence of slip between the crystal and the sleeves. One end of the crystal was screwed into the brass plate and the other end into a holder to which a heavy wire cable was attached. This wire extended over ball bearing pulleys to a platform which supported the weights used to stretch the crystal.

The extension of the crystal was measured as follows: A thin stainless steel cylinder with lucite ends to reduce heat conduction rested on the crystal, and extended through the hole in the top of the wooden structure. The top end of this cylinder was fitted into a steel piston 3.810 cm. in diameter, which in turn fitted snugly with as little friction as possible into a cylinder from which protruded a capillary tube 0.249 cm. in diameter. The cylinder and part of the tube were filled with mercury, so that any extension of the crystal caused the mercury to rise in the tube. This arrangement gave a magnification of 234.2 for the increase in length of the crystal. The rise of mercury in the



capillary tube was measured to  $\pm 0.005$  cm. by means of a cathetometer, so that the extension of the crystal could be measured to about  $\pm 2 \times 10^{-5}$  cm..

A photograph of the apparatus used for measurement of the torsion modulus is shown in figure 2. It consisted of a wooden structure with a heavy brass cylinder about 22 cm. long and 4.5 cm. in diameter fastened securely to the under side of the top. A heavy brass disc was fastened securely to the bottom of the cylinder. The crystal, with the same end pieces as used in the Young's modulus apparatus attached to it, was threaded into the disc. The other end of the crystal was threaded into a solid brass cylinder approximately 1.9 cm. in diameter, which passed through a ball bearing sleeve in the top of the apparatus. A couple arm 26.0 cm. long was passed horizontally through the cylinder near its top. Cords attached to the ends of the couple arm passed over pulleys to the weight pans. A mirror and lens were attached to the cylinder above the couple arm, and a beam of light was reflected from this optical system to a scale one meter from the mirror. This arrangement gave ample accuracy for measurements of the angle of twist of the crystal.

The Young's modulus apparatus was tested with a steel wire 0.150 cm. in diameter, annealed at  $450^{\circ}$  C. This was fastened into the apparatus in the same manner as the single crystal samples, using brass end pieces and silver solder. There appeared to be a small amount of hysteresis on unloading, but the wire returned to its original length after all the load was removed, and the readings of the mercury level reproduced within 0.02 cm. on a second cycle. The descending curve remained parallel to the ascending curve except at the two ends. Since polycrystalline steel should be perfectly elastic, it was concluded that the small difference between loading and unloading was due to a change in the mercury meniscus according as the column was rising or falling, amounting to not more than 0.05 cm. The Young's modulus of the steel, deduced from the straight portions of the curves, was  $18.2 \times 10^{11}$  dynes/cm<sup>2</sup>.





Front View



Side View

Fig. 1. Apparatus Used for the Measurement of Young's Modulus





Front View



Side View

Fig. 2. Apparatus Used for the Measurement of Torsion Modulus



#### IV EXPERIMENTAL PROCEDURE AND RESULTS

Each of the untreated crystals was fastened in turn into the apparatus for the Young's modulus and the torsion modulus. Weights were added until the elastic limit was barely reached. As each weight was added a reading of the extension or angular twist (depending upon which experiment was being performed) was taken. The weights were removed in the same order as they were added and readings taken as for the addition of the weights. In nearly all cases there was a two-minute interval between addition or removal of weights. In the first few trials a five-minute interval was taken, but it was observed that no change occurred over the last three minutes, so the interval was reduced to two minutes. Three or four series of readings were taken in each case both at room and liquid nitrogen temperatures. For the last set of readings in each series more weights were added than in the previous sets, and the elastic limit was exceeded in cases where the danger of fracturing the crystal was small.

The crystals were given various heat treatments after which measurements of the change in length and angle of twist with load were taken as previously described. The heat treatments were not the same for all crystals. The beta-brass was given the following heat treatments:

- (a) annealed at  $500^{\circ}$  C
- (b) heated at  $500^{\circ}$  C and quenched in oil
- (c) heated at  $500^{\circ}$  C, cooled slowly to  $450^{\circ}$  C and then quenched
- (d) heated at  $500^{\circ}$  C, cooled to  $400^{\circ}$  C and quenched
- (e) heated at  $575^{\circ}$  C and quenched in oil.

The copper crystal was annealed at  $195^{\circ}$  C and  $500^{\circ}$  C; the zinc was annealed at  $100^{\circ}$  C, and the magnesium and aluminum at  $200^{\circ}$  C. In each of the heating processes the crystal was kept at the specified temperatures for one hour.

The diameters and lengths of the crystals were measured to the nearest 0.001 cm. and 0.01 cm. respectively. The



values of these measurements are given in table 1. In the Young's modulus part of the experiment, a correction was made for the change in pressure due to the rise of mercury in the capillary tube. In the calculation of the elastic limit for this part of the experiment the weight of the scale pan, mercury, piston and supporting cylinder were all taken into account.

The values of the loads in grams and the changes in length of the crystals in centimeters for the Young's modulus experiment are given in tables I to XXVII inclusive. The values of the torques in gram centimeters and the angles of twist of the crystals in radians for the torsion modulus experiment are given in tables XXVIII to XLVIII inclusive. The graphs for the loads versus change in length and torque versus angle of twist plotted from the tables are shown in figures I to XXVII and XXVIII to XLVIII respectively. The points ., +, e and o on the graphs represent the values from the first, second, third and fourth sets of readings respectively, where more than one set of readings was taken. The Young's and torsion moduli were calculated from the slopes of the straight portions of the graphs.

The Young's modulus was calculated from the relation

$$Y = \frac{l}{A} \cdot \frac{dF}{de}$$

where F is the applied force in dynes,  $l$  is the length of the crystal in centimeters, A is the cross-sectional area of the crystal in square centimeters and e the elongation of the crystal in centimeters.

The torsion modulus was calculated from the relation

$$n = \frac{2l}{\pi R^4} \cdot \frac{dL}{d\theta}$$

where L is the applied torque in cm. dynes,  $l$  is the length of the crystal in centimeters, R is the radius of cross-section of the crystal in centimeters, and  $\theta$  is the angular twist in radians.



TABLE 1. Diameters and Lengths of Crystals

<u>Crystal</u>	<u>Diameter</u> (cm.)	<u>Length</u> (cm.)
Brass	0.520	12.75
Copper	0.316	12.67
Zinc	0.316	12.80 and 11.40
Aluminum	0.400	12.95
Magnesium	0.308	12.75

The tensile elastic limit was found by taking the value of the stress from the graph where the slope began to decrease and adding to this the initial stress caused by the resultant force due to the scale pan, mercury, piston and supporting cylinder weights.

The torsion elastic limit, or critical shearing stress was found from the relation

$$S_c = \frac{nR\theta_c}{l}$$

where  $\theta_c$  is the critical angle of twist of the crystal in radians. The value of  $\theta_c$  was taken from the graph and was the value of  $\theta$  for which the slope of the graph began to decrease.

The values of the Young's and torsion moduli as well as the values of the elastic limits of the crystals in the various states are given in tables XLIX to LVII. The effects of annealing and low temperature upon the elastic moduli and the elastic limits of the single crystals are outlined in tables LVIII and LIX.

Laue photographs were taken of samples of the crystals about 1 mm. thick cut at right angles to the rods in order to determine the angle of tilt of the crystal axis with the axis of the sample and one of the principal planes of the

# THE HISTORY OF THE

Year	Event	Location
1776	Declaration of Independence	Philadelphia
1781	British evacuated Philadelphia	Philadelphia
1783	Evacuation of the city	Philadelphia
1787	Constitutional Convention	Philadelphia
1791	Adoption of the Constitution	Philadelphia

The following table shows the population of the city of Philadelphia from 1776 to 1800. The population was 25,000 in 1776, 30,000 in 1780, 35,000 in 1790, and 40,000 in 1800. The population was 45,000 in 1810, 50,000 in 1820, 55,000 in 1830, and 60,000 in 1840. The population was 65,000 in 1850, 70,000 in 1860, 75,000 in 1870, and 80,000 in 1880. The population was 85,000 in 1890, 90,000 in 1900, 95,000 in 1910, and 100,000 in 1920.

The following table shows the population of the city of Philadelphia from 1776 to 1800. The population was 25,000 in 1776, 30,000 in 1780, 35,000 in 1790, and 40,000 in 1800. The population was 45,000 in 1810, 50,000 in 1820, 55,000 in 1830, and 60,000 in 1840. The population was 65,000 in 1850, 70,000 in 1860, 75,000 in 1870, and 80,000 in 1880. The population was 85,000 in 1890, 90,000 in 1900, 95,000 in 1910, and 100,000 in 1920.

crystal. The crystal axis of the beta-brass was found to make an angle of  $5.5^{\circ}$  with the axis of the sample and to be tilted in a direction making an angle of  $7.0^{\circ}$  with the assumed (100) plane of the crystal. The method used for the identification of the crystal axis from the Laue photographs is described in the appendix using the Laue photograph of the beta-brass as an example.

The crystal axis of the copper was found to make an angle of  $5.9^{\circ}$  with the axis of the sample, and to be tilted in a direction making an angle of  $15^{\circ}$  with the (100) plane. The spots on the copper photograph were all considerably elongated, which indicated a certain amount of internal warping.

The hexagonal axis of the zinc crystal was found to make an angle of  $1.9^{\circ}$  with the axis of the sample in a plane at  $45^{\circ}$  to a secondary crystal axis.

The Laue photograph of the aluminum crystal showed that it was approximately axial. The reflections were very streaky, which indicated internal warping of the crystal lattice.

The Laue photograph of the magnesium consisted of a cloud of very small spots which seemed to indicate a great deal of twinning, so that it was doubtful whether it could be considered a single crystal.

Two additional X-ray photographs of samples cut from different places in the crystal rods were taken for each crystal after all other experiments had been completed. Near the beginning of the experiment two transverse pictures of each of the copper and zinc rods were taken. All these photographs, with the exception of the ones for magnesium, showed that the samples were single crystals.

The values of the Young's moduli given in tables XLIX to LIII are accurate within an error of  $\pm 2.0\%$ . This error was



calculated by taking into account the maximum possible errors involved in the measurements of the diameters and extensions of the crystals. The values of the torsion moduli given in tables LIV to LVII are accurate within an error of  $\pm 1.0\%$ . This error was calculated by taking into account the maximum possible errors involved in the measurements of the diameters and angular twists of the crystals.

The lengths of the crystals given in table I did not include the portions of the crystals within the holders. No correction was made for the latter portions. Because of the fact that the crystals were fitted snugly into the holders and held by a thin layer of solder, these portions of the crystals could be considered as part of the holders. The stretch of the holders, including the ends of the crystals, was neglected since the diameters of the holders were much larger than those of the crystals.

There is some scattering of the points in the graphs. The scatter of the points in a single trial is, in nearly all cases, within the experimental error of  $\pm 1.0\%$  for the measurement of the distortion of the crystal. The graphs of repeated trials in many cases do not follow the same line, but give lines parallel to one another. An extreme example of this is shown in figure III, where four trials were made without taking readings for unloading, with the exception of the last trial. It appears that such a behaviour was caused by some permanent distortion within the crystal.



TABLE I. Brass Crystal as Received. Temperature 24.0° C.

Load $10^4$ gm.	Elongation $10^{-3}$ cm.	Load $10^4$ gm.	Elongation $10^{-3}$ cm.	Load $10^4$ gm.	Elongation $10^{-3}$ cm.
0	0	0	0	0	0
0.337	0.427	0.338	0.30	0.338	0.235
0.674	0.984	0.674	1.05	0.674	0.940
1.01	1.50	1.01	1.84	1.01	1.67
1.11	1.56	1.34	2.60	1.35	2.77
1.21	1.65	1.67	3.24	1.68	3.57
1.31	1.82	1.77	3.46	2.00	4.23
1.41	1.99	1.87	3.68	2.34	4.97
1.51	2.16	1.97	3.83	2.68	5.78
1.61	2.37	2.07	4.03	3.01	6.66
1.71	2.63	2.17	4.28	3.11	6.98
1.81	2.86	2.27	4.50	3.21	7.28
1.91	3.14	2.36	4.75	3.31	7.54
2.00	3.40	2.46	5.10	3.41	7.77
2.10	3.67	2.56	5.35	3.51	8.07
2.20	3.98			3.61	8.37
				3.71	8.67
				3.80	8.94
				3.90	9.26
				4.00	9.56
				4.10	9.85
				4.20	10.2



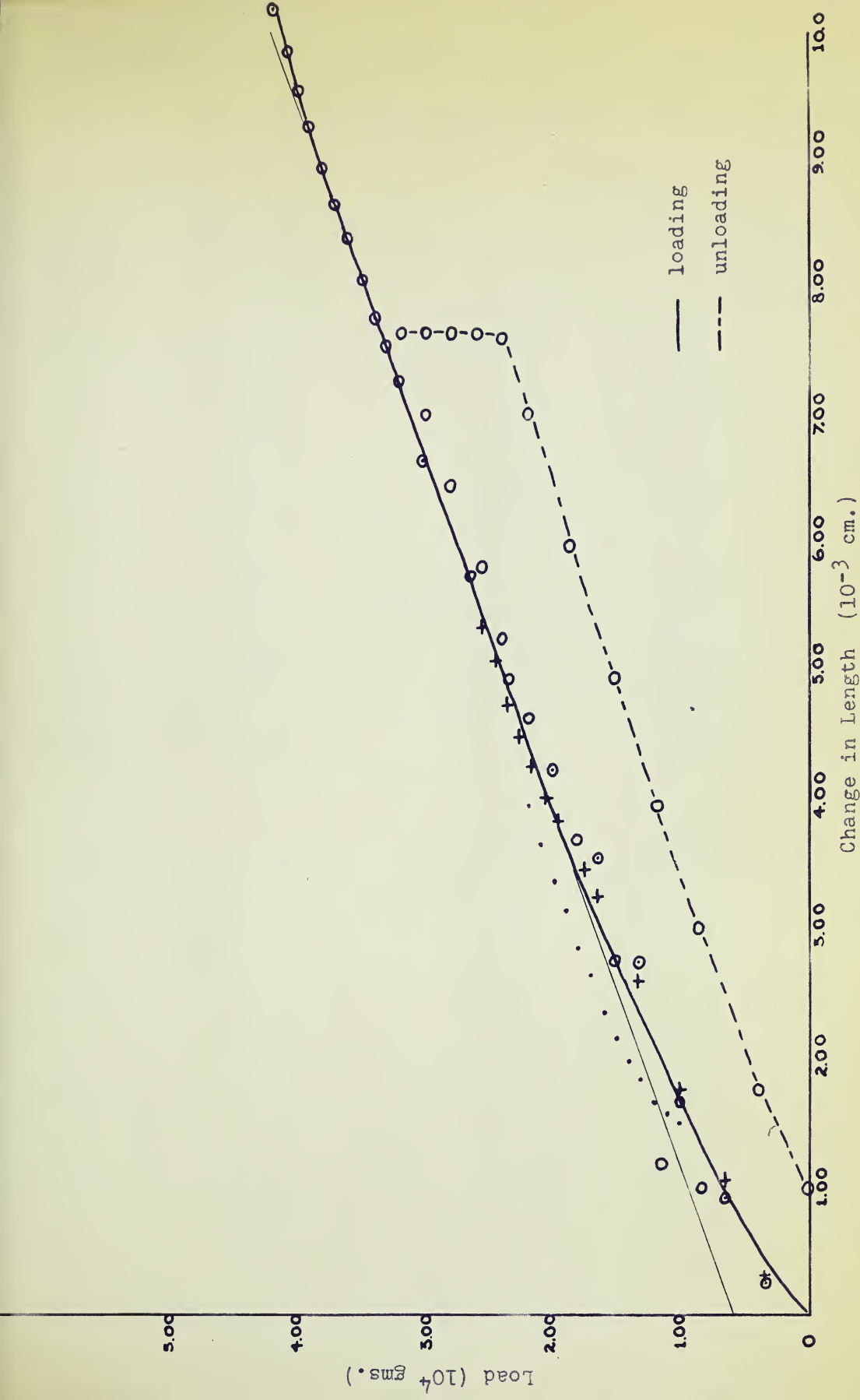


Fig. I. Brass Crystal as Received. Temperature  $24.0^\circ\text{C}$ .



TABLE II. Brass Crystal Annealed at 500° C. Temperature 28.1° C.

<u>Loading</u>		<u>Unloading</u>	
Load	Change in Length	Load	Change in Length
$10^4$ gms.	$10^{-3}$ cm.	$10^4$ gms.	$10^{-3}$ cm.
0	0	2.40	3.63
0.337	0.534	2.20	3.59
0.674	1.09	2.00	3.50
1.01	1.60	1.81	3.16
1.21	1.91	1.61	2.82
1.41	2.18	1.41	2.52
1.61	2.48	1.21	2.16
1.81	2.76	1.01	1.79
2.01	3.01	0.673	1.55
2.20	3.31	0.337	0.469
2.40	3.63	0	0.128
0	0	2.40	3.87
0.338	0.363	2.20	3.59
0.675	0.833	2.00	3.05
1.01	1.31	1.81	2.63
1.21	1.60	1.61	2.25
1.41	1.93	1.41	1.88
1.61	2.31	1.21	1.56
1.81	2.70	1.01	1.22
2.01	3.05	0.675	0.862
2.20	3.44	0.338	0.384
2.40	3.87	0	0.128



TABLE II cont'd. Brass Crystal Annealed at 500° C. Temperature 28.1°C.

<u>Loading</u>		<u>Unloading</u>	
Load	Change in Length	Load	Change in Length
$10^4$ gms.	$10^{-3}$ cm.	$10^4$ gms.	$10^{-3}$ cm.
0	0	2.40	3.64
0.338	0.214	2.20	3.42
0.676	0.512	2.01	2.84
1.01	1.03	1.81	2.42
1.21	1.37	1.61	2.09
1.41	1.75	1.41	1.67
1.61	2.10	1.21	1.30
1.81	2.52	1.01	1.07
2.01	2.89	0.676	0.684
2.20	3.27	0.338	0.171
2.40	3.64	0	0



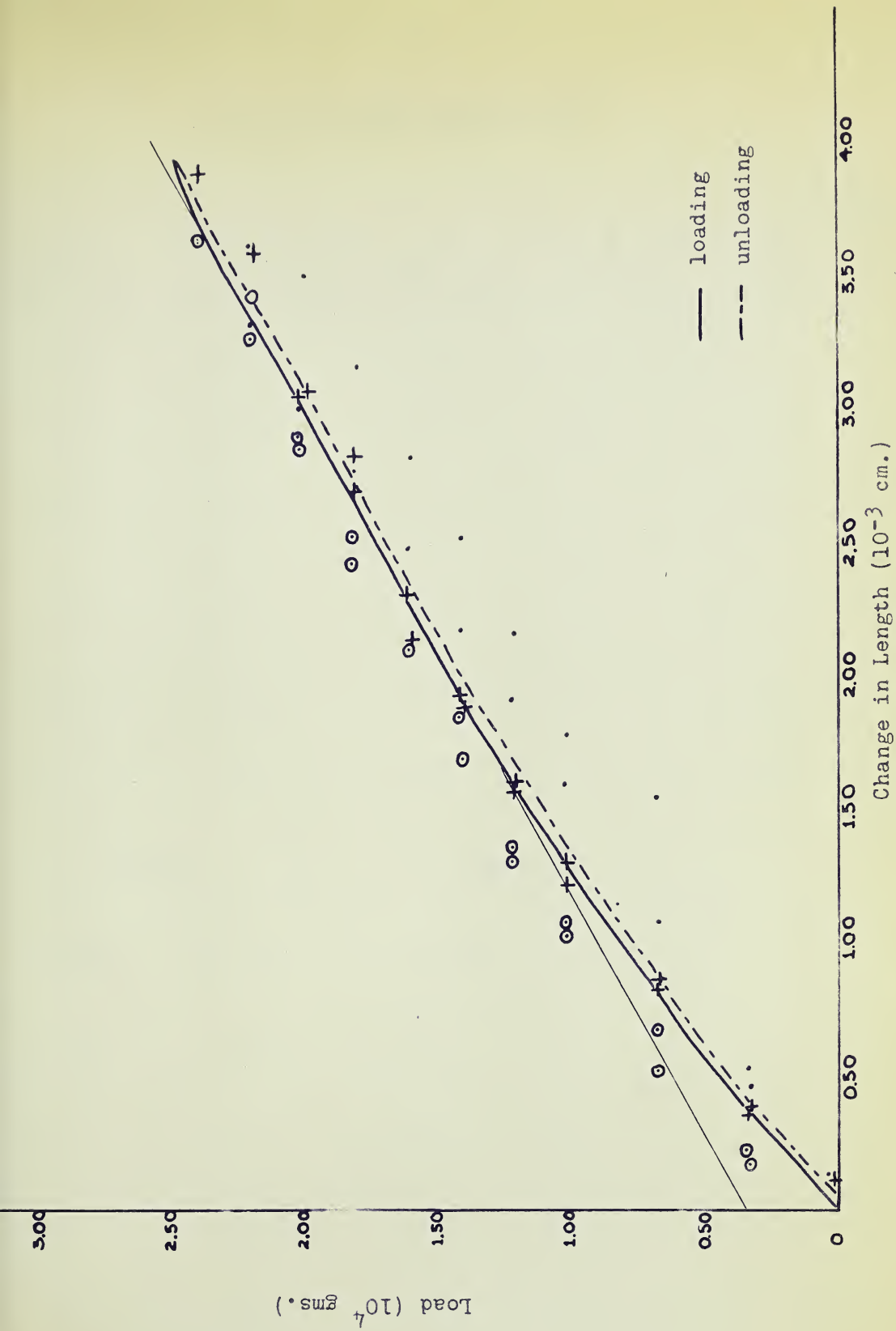


Fig. II. Brass Crystal Annealed at  $500^{\circ}\text{C}$ . Temperature  $28.1^{\circ}\text{C}$ .



Table III. Brass Crystal Annealed at 500° C.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Loading</u>		<u>Loading</u>	
Load	Change in Length	Load	Change in Length	Load	Change in Length
$10^4$ gms.	$10^{-3}$ cm.	$10^4$ gms.	$10^{-3}$ cm.	$10^4$ gms.	$10^{-3}$ cm.
0	0	0	0	0	0
0.339	0.000	0.338	0.384	0.338	0.128
0.676	0.469	0.674	1.11	0.676	0.640
1.01	1.18	1.01	1.77	1.01	1.32
1.21	1.58	1.21	2.22	1.21	1.75
1.41	1.99	1.41	2.65	1.41	2.07
1.61	2.43	1.61	2.97	1.61	2.48
1.81	2.86	1.80	3.40	1.81	2.88
2.01	3.21	2.00	3.81	2.01	3.29
2.20	3.60	2.20	4.25	2.20	3.65
2.40	3.89	2.40	4.63	2.40	3.91

<u>Loading</u>		<u>Unloading</u>	
Load	Change in Length	Load	Change in Length
$10^4$ gms.	$10^{-3}$ cm.	$10^4$ gms.	$10^{-3}$ cm.
0	0	2.40	5.22
0.336	0.940	2.20	5.22
0.672	1.62	2.00	5.20
1.01	2.31	1.80	5.16
1.21	2.74	1.60	4.78
1.41	3.12	1.40	4.02
1.60	3.51	1.20	3.53
1.80	3.94	1.01	2.95
2.00	4.36	0.670	2.18
2.20	4.78	0.333	1.62
2.40	5.22	-0.005	1.35



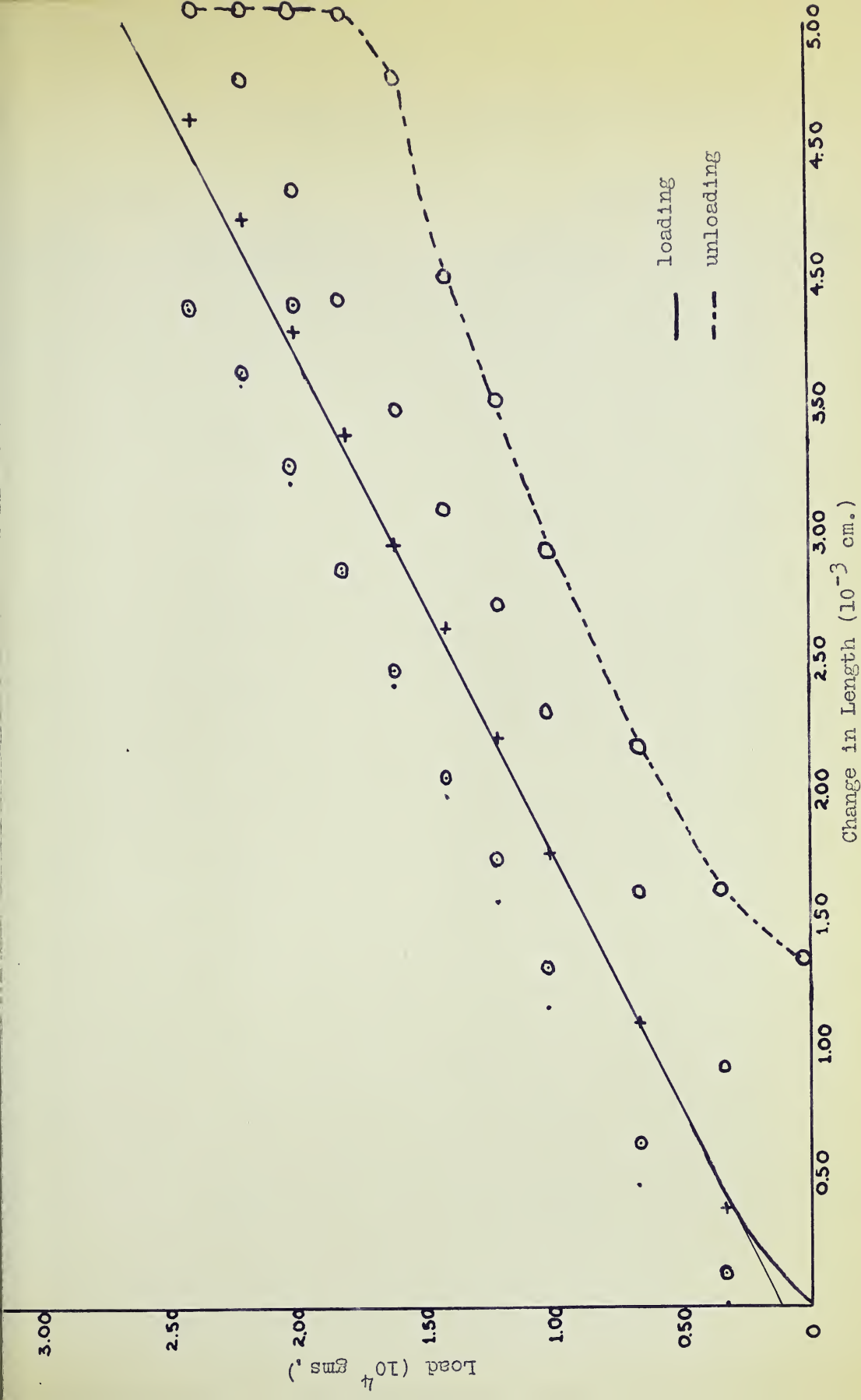


Fig. III. Brass Crystal Annealed at 500° C. Liquid Nitrogen Temperature



TABLE IV. Brass Crystal Heated at 500° C. and Quenched.  
Temperature 22.5° C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>gms. 10<sup>4</sup></u>	<u>Change in Length</u> <u>cm. 10<sup>-3</sup></u>	<u>Load</u> <u>gms. 10<sup>4</sup></u>	<u>Change in Length</u> <u>cm. 10<sup>-3</sup></u>
0	0	2.40	4.38
0.339	0.000	2.20	4.15
0.676	0.469	2.00	3.67
1.01	1.22	1.81	3.25
1.21	1.52	1.61	2.80
1.41	1.99	1.41	2.39
1.61	2.44	1.21	1.96
1.81	2.91	1.01	1.69
2.00	3.38	0.673	1.33
2.20	3.89	0.334	1.28
2.40	4.38	-0.004	1.24
0	0	2.40	4.67
0.339	0.043	2.20	4.61
0.676	0.662	2.00	4.13
1.01	1.47	1.80	3.76
1.21	1.75	1.61	3.27
1.41	2.33	1.41	2.78
1.61	2.73	1.21	2.44
1.81	3.27	1.01	2.14
2.00	3.72	0.671	1.92
2.20	4.18	0.333	1.84
2.40	4.67	-0.006	1.80



TABLE IV cont'd. Brass Crystal Heated at 500° C. and Quenched.  
Temperature 22.5° C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>gms. 10<sup>4</sup></u>	<u>Change in Length</u> <u>cm. 10<sup>-3</sup></u>	<u>Load</u> <u>gms. 10<sup>4</sup></u>	<u>Change in Length</u> <u>cm. 10<sup>-3</sup></u>
0	0	2.80	5.62
0.339	0.000	2.60	5.57
0.676	0.406	2.40	5.32
1.01	1.07	2.20	4.74
1.21	1.62	2.00	4.39
1.41	2.07	1.80	3.87
1.61	2.61	1.60	3.40
1.81	3.12	1.41	3.01
2.00	3.48	1.21	2.54
2.20	4.02	1.01	2.26
2.40	4.50	0.671	1.88
2.60	5.02	0.333	1.81
2.80	5.62	-0.006	1.81



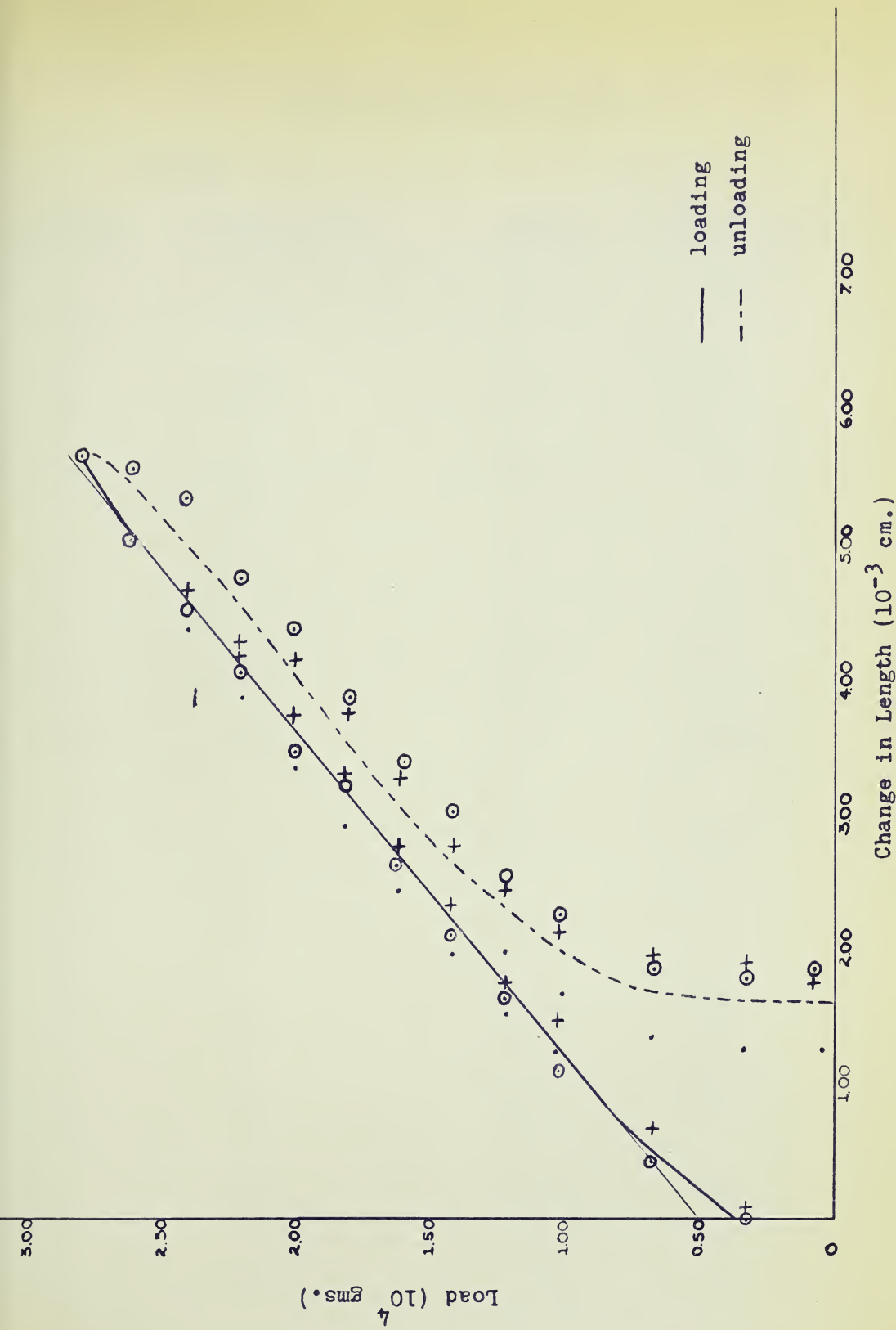


Fig. IV. Brass Crystal Heated at 500° C. and Quenched. Temperature 22.5° C.



TABLE V. Brass Crystal Heated at 500° C. and Quenched.  
Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	2.40	5.60
0.339	0.320	2.20	5.57
0.674	1.20	2.00	5.14
1.01	2.16	1.80	4.57
1.21	2.54	1.60	3.96
1.41	3.03	1.40	3.44
1.60	3.57	1.21	2.93
1.80	4.15	1.01	2.29
2.00	4.58	0.672	1.60
2.20	5.06	0.336	0.917
2.40	5.60	0	0.021
0	0	2.40	5.80
0.339	0.384	2.20	5.70
0.674	1.15	2.00	5.23
1.01	2.12	1.80	4.61
1.21	2.65	1.60	4.14
1.41	3.20	1.40	3.68
1.60	3.74	1.21	3.03
1.80	4.21	1.01	
2.00	4.75	0.672	1.62
2.20	5.25	0.335	1.15
2.40	5.80	0	0



TABLE V. cont'd. Brass Crystal Heated at 500°C. and Quenched.  
Liquid Nitrogen Temperature.

<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Loading</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0		0
0.338		0.448
0.674		1.45
1.01		2.35
1.21		2.99
1.40		3.52
1.60		3.97
1.80		4.53
2.00		5.08
2.20		5.65
2.40		6.15
2.59		6.66
2.79		7.17
2.99		7.68
3.19		8.13
3.39		8.58
3.58		9.18
3.78		9.65
3.98		10.3
4.18		10.6
4.38		11.1
4.58		11.7
4.77		12.2
4.97		12.8
5.17		13.3
5.37		13.8
5.57		14.3
5.86		15.0



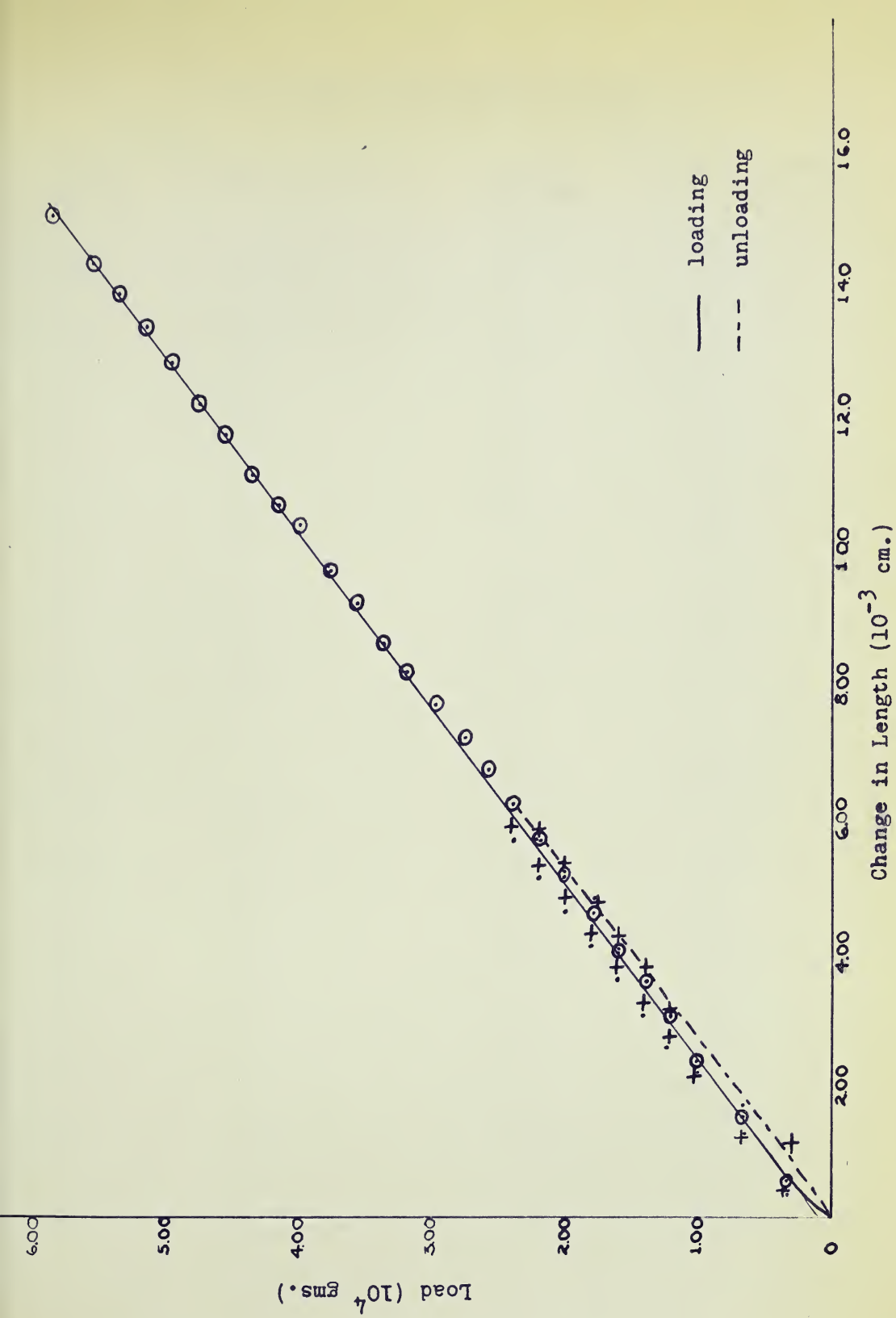


Fig. V. Brass Crystal Heated at 500° C. and Quenched. Liquid Nitrogen Temperature.



TABLE VI. Brass Crystal Annealed at 500°C. and Quenched  
from 450°C. Temperature 22.1°C.

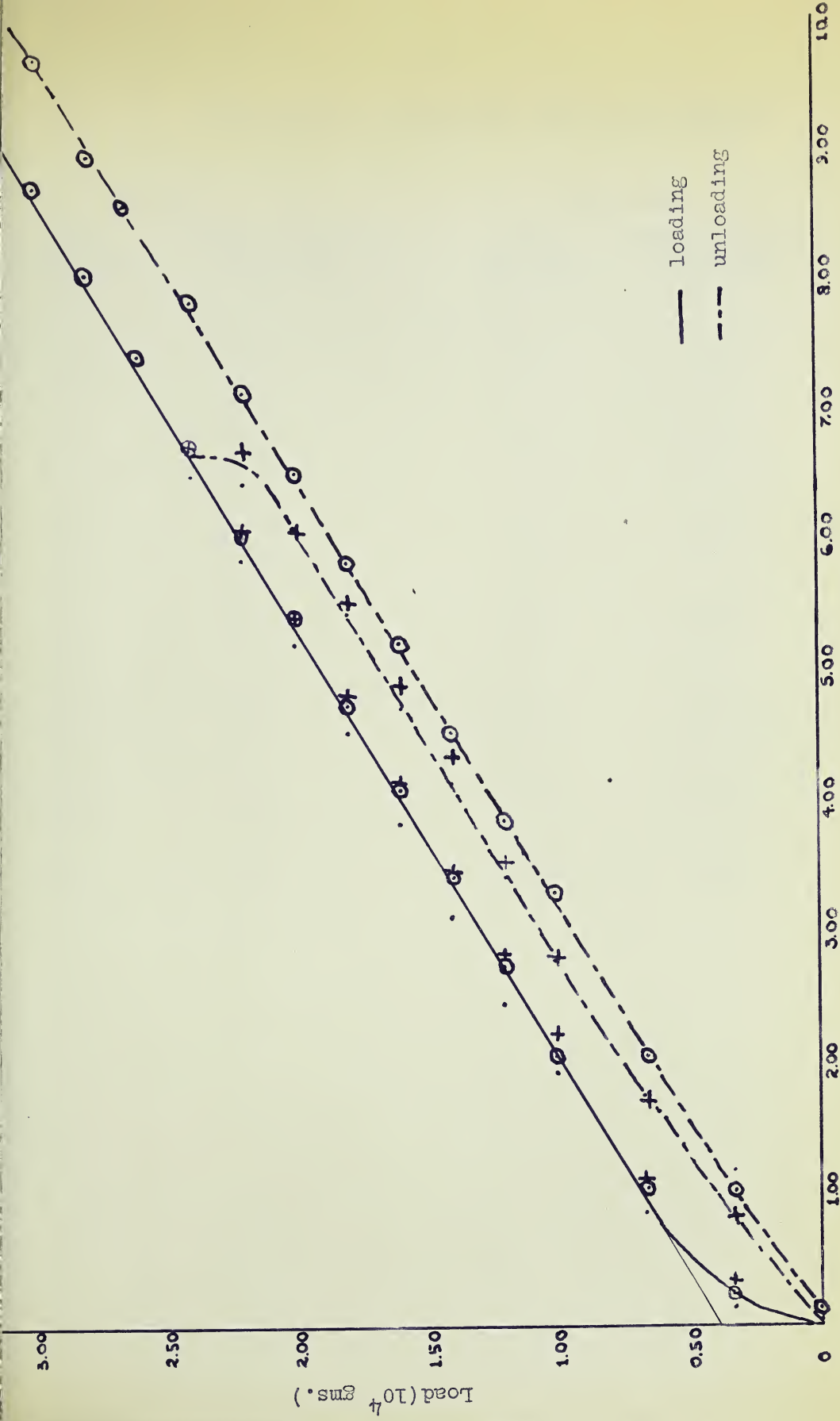
<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	2.39	6.51
0.338	0.128	2.19	6.45
0.675	0.896	2.00	6.10
1.01	1.97	1.80	5.48
1.21	2.46	1.60	4.72
1.41	3.16	1.40	4.18
1.60	3.86	1.20	3.46
1.80	4.55	1.01	2.80
2.00	5.21	0.672	1.79
2.20	5.87	0.335	1.20
2.39	6.51	0	0
0	0	2.39	6.75
0.338	0.364	2.19	6.70
0.674	1.13	1.99	6.08
1.01	2.24	1.80	5.55
1.21	2.86	1.60	4.91
1.40	3.48	1.40	4.18
1.60	4.17	1.20	3.57
1.80	4.82	1.01	2.82
2.00	5.43	0.672	1.76
2.19	6.09	0.336	0.812
2.39	6.75	0	0.064



TABLE VI. cont'd. Brass Crystal Annealed at 500°C. and Quenched from 450°C. Temperature 22.1°C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	3.58	10.7
0.338	0.256	3.38	10.6
0.674	1.09	3.18	10.1
1.01	2.09	2.98	9.75
1.21	2.78	2.78	8.97
1.40	3.46	2.59	8.60
1.60	4.12	2.39	7.88
1.80	4.78	2.19	7.18
2.00	5.44	1.99	6.54
2.20	6.05	1.80	5.87
2.39	6.75	1.60	5.22
2.59	7.44	1.40	4.55
2.79	8.07	1.20	3.87
2.99	8.72	1.01	3.32
3.18	9.35	0.671	2.08
3.38	10.0	0.335	1.03
3.58	10.7	0	0.107





Change in Length ( $10^{-3}$  cm.)

Fig. VI. Brass Crystal Annealed at  $500^{\circ}$  C. and Quenched from  $450^{\circ}$  C.  
Temperature  $22.1^{\circ}$  C.



TABLE VII. Brass Crystal Annealed at 500°C. and Quenched from 450°C. Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	2.99	7.77
0.337	0.427	2.79	7.73
0.673	1.35	2.59	7.32
1.01	2.20	2.39	6.83
1.21	2.78	2.19	6.28
1.40	3.38	2.00	5.80
1.60	3.98	1.80	5.21
1.80	4.55	1.60	4.61
2.00	5.17	1.40	4.05
2.20	5.89	1.20	3.36
2.39	6.53	1.01	2.88
2.59	6.90	0.673	1.79
2.79	7.35	0.335	1.20
2.99	7.77	-0.002	0.470



TABLE VII. cont'd. Brass Crystal Annealed at 500°C. and Quenched from 450°C. Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	2.99	7.70
0.338	0.342	2.79	7.57
0.675	1.07	2.59	7.17
1.01	1.84	2.39	6.56
1.21	2.67	2.20	5.97
1.40	3.42	2.00	5.55
1.60	4.06	1.80	4.82
1.80	4.59	1.60	4.29
2.00	5.03	1.40	3.65
2.20	5.60	1.21	3.12
2.40	6.02	1.01	2.61
2.59	6.53	0.671	2.01
2.79	7.13	0.335	1.15
2.99	7.70	0	0.171
0	0	2.99	7.47
0.338	0.214	2.79	7.43
0.675	0.832	2.59	7.09
1.01	2.01	2.39	6.58
1.21	2.46	2.20	5.85
1.41	3.25	2.00	5.32
1.60	3.72	1.80	4.74
1.80	4.31	1.60	4.06
2.00	4.95	1.40	3.55
2.20	5.55	1.21	3.03
2.40	6.10	1.01	2.48
2.59	6.60	0.670	2.16
2.79	7.00	0.335	0.790
2.99	7.47	- 0.001	0.320

# THE JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION PUBLISHED WEEKLY CHICAGO, ILL., U.S.A. 1917

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32
33	34	35	36
37	38	39	40
41	42	43	44
45	46	47	48
49	50	51	52
53	54	55	56
57	58	59	60
61	62	63	64
65	66	67	68
69	70	71	72
73	74	75	76
77	78	79	80
81	82	83	84
85	86	87	88
89	90	91	92
93	94	95	96
97	98	99	100
101	102	103	104
105	106	107	108
109	110	111	112
113	114	115	116
117	118	119	120
121	122	123	124
125	126	127	128
129	130	131	132
133	134	135	136
137	138	139	140
141	142	143	144
145	146	147	148
149	150	151	152
153	154	155	156
157	158	159	160
161	162	163	164
165	166	167	168
169	170	171	172
173	174	175	176
177	178	179	180
181	182	183	184
185	186	187	188
189	190	191	192
193	194	195	196
197	198	199	200
201	202	203	204
205	206	207	208
209	210	211	212
213	214	215	216
217	218	219	220
221	222	223	224
225	226	227	228
229	230	231	232
233	234	235	236
237	238	239	240
241	242	243	244
245	246	247	248
249	250	251	252
253	254	255	256
257	258	259	260
261	262	263	264
265	266	267	268
269	270	271	272
273	274	275	276
277	278	279	280
281	282	283	284
285	286	287	288
289	290	291	292
293	294	295	296
297	298	299	300
301	302	303	304
305	306	307	308
309	310	311	312
313	314	315	316
317	318	319	320
321	322	323	324
325	326	327	328
329	330	331	332
333	334	335	336
337	338	339	340
341	342	343	344
345	346	347	348
349	350	351	352
353	354	355	356
357	358	359	360
361	362	363	364
365	366	367	368
369	370	371	372
373	374	375	376
377	378	379	380
381	382	383	384
385	386	387	388
389	390	391	392
393	394	395	396
397	398	399	400
401	402	403	404
405	406	407	408
409	410	411	412
413	414	415	416
417	418	419	420
421	422	423	424
425	426	427	428
429	430	431	432
433	434	435	436
437	438	439	440
441	442	443	444
445	446	447	448
449	450	451	452
453	454	455	456
457	458	459	460
461	462	463	464
465	466	467	468
469	470	471	472
473	474	475	476
477	478	479	480
481	482	483	484
485	486	487	488
489	490	491	492
493	494	495	496
497	498	499	500
501	502	503	504
505	506	507	508
509	510	511	512
513	514	515	516
517	518	519	520
521	522	523	524
525	526	527	528
529	530	531	532
533	534	535	536
537	538	539	540
541	542	543	544
545	546	547	548
549	550	551	552
553	554	555	556
557	558	559	560
561	562	563	564
565	566	567	568
569	570	571	572
573	574	575	576
577	578	579	580
581	582	583	584
585	586	587	588
589	590	591	592
593	594	595	596
597	598	599	600
601	602	603	604
605	606	607	608
609	610	611	612
613	614	615	616
617	618	619	620
621	622	623	624
625	626	627	628
629	630	631	632
633	634	635	636
637	638	639	640
641	642	643	644
645	646	647	648
649	650	651	652
653	654	655	656
657	658	659	660
661	662	663	664
665	666	667	668
669	670	671	672
673	674	675	676
677	678	679	680
681	682	683	684
685	686	687	688
689	690	691	692
693	694	695	696
697	698	699	700
701	702	703	704
705	706	707	708
709	710	711	712
713	714	715	716
717	718	719	720
721	722	723	724
725	726	727	728
729	730	731	732
733	734	735	736
737	738	739	740
741	742	743	744
745	746	747	748
749	750	751	752
753	754	755	756
757	758	759	760
761	762	763	764
765	766	767	768
769	770	771	772
773	774	775	776
777	778	779	780
781	782	783	784
785	786	787	788
789	790	791	792
793	794	795	796
797	798	799	800
801	802	803	804
805	806	807	808
809	810	811	812
813	814	815	816
817	818	819	820
821	822	823	824
825	826	827	828
829	830	831	832
833	834	835	836
837	838	839	840
841	842	843	844
845	846	847	848
849	850	851	852
853	854	855	856
857	858	859	860
861	862	863	864
865	866	867	868
869	870	871	872
873	874	875	876
877	878	879	880
881	882	883	884
885	886	887	888
889	890	891	892
893	894	895	896
897	898	899	900
901	902	903	904
905	906	907	908
909	910	911	912
913	914	915	916
917	918	919	920
921	922	923	924
925	926	927	928
929	930	931	932
933	934	935	936
937	938	939	940
941	942	943	944
945	946	947	948
949	950	951	952
953	954	955	956
957	958	959	960
961	962	963	964
965	966	967	968
969	970	971	972
973	974	975	976
977	978	979	980
981	982	983	984
985	986	987	988
989	990	991	992
993	994	995	996
997	998	999	1000

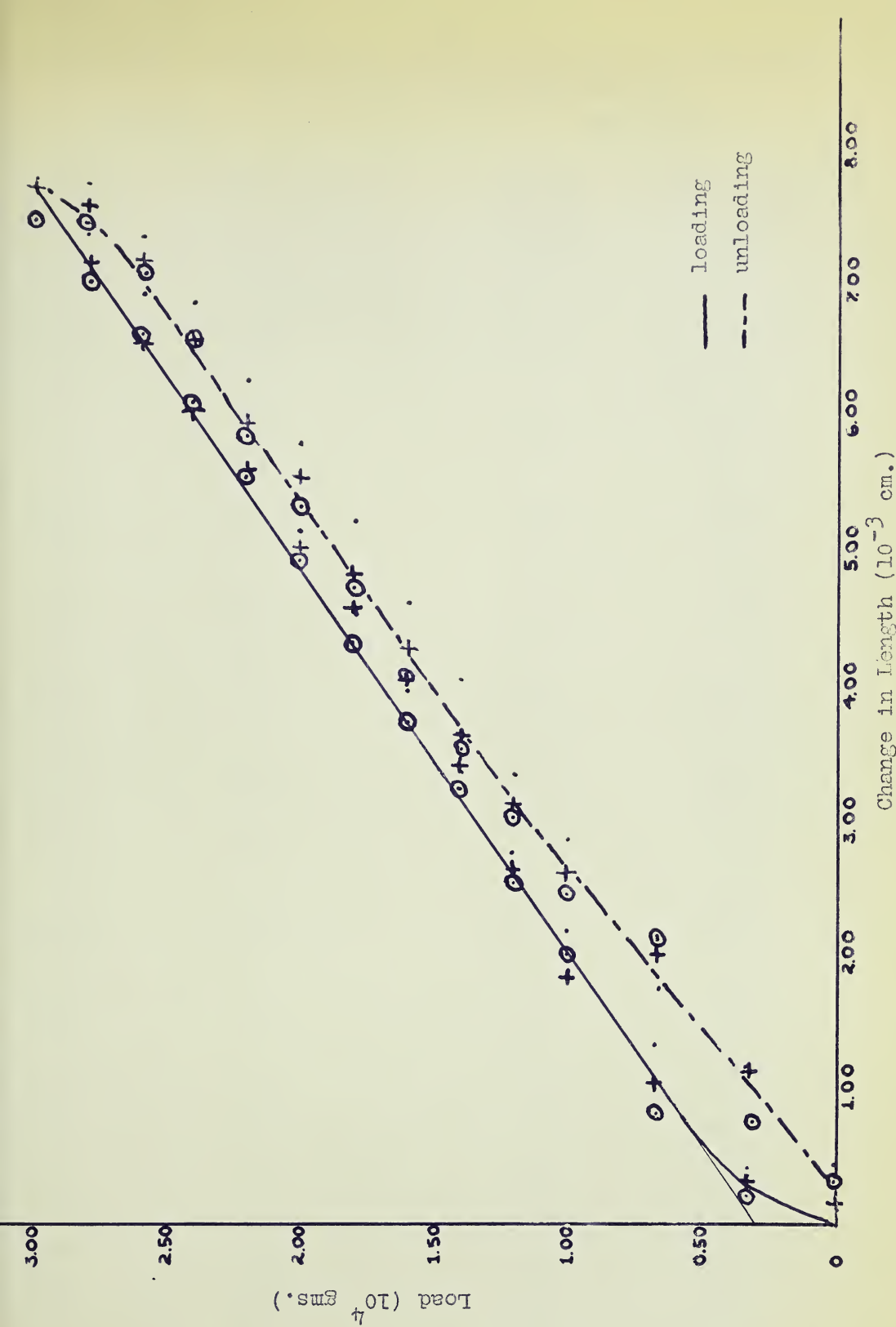


Fig. VII. Brass Crystal Annealed at  $500^{\circ}$  C. and quenched from  $450^{\circ}$  C.  
Liquid Nitrogen Temperature



TABLE VIII. Brass Crystal Annealed at 500°C. and Quenched from 400°C. Temperature 22.4°C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	2.99	7.27
0.337	0.620	2.79	7.22
0.673	1.46	2.59	7.17
1.01	2.33	2.39	6.54
1.21	2.78	2.20	6.07
1.41	3.27	2.00	5.71
1.60	3.76	1.80	5.21
1.80	4.19	1.60	4.85
2.00	4.65	1.40	4.42
2.20	5.15	1.20	3.94
2.40	5.79	1.00	3.46
2.59	6.22	0.668	2.74
2.79	6.75	0.331	2.14
2.99	7.27	-0.005	1.29
0	0	2.99	6.94
0.337	0.533	2.79	6.90
0.674	1.11	2.59	6.86
1.01	2.20	2.39	6.53
1.21	2.54	2.20	5.89
1.41	2.99	2.00	5.33
1.60	3.42	1.80	4.92
1.80	3.97	1.60	4.50
2.00	4.40	1.40	4.18
2.20	4.91	1.20	3.70
2.40	5.47	1.00	3.31
2.60	5.91	0.669	2.42
2.79	6.45	0.333	1.80
2.99	6.94	-0.003	0.983

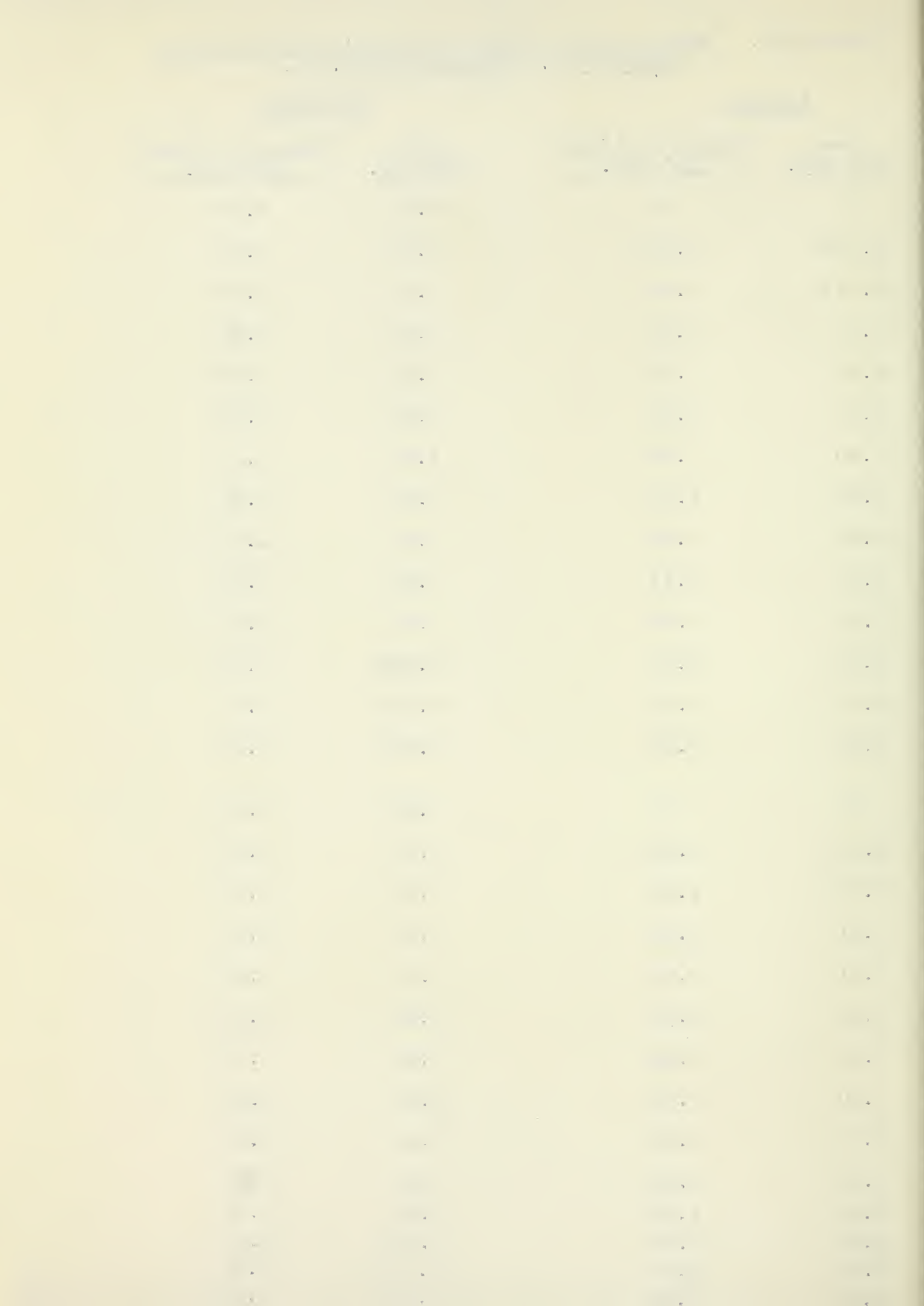


TABLE VIII. cont'd. Brass Crystal Annealed at 500°C. and Quenched  
from 400°C. Temperature 22.4°C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	3.39	8.13
0.337	0.661	3.19	8.11
0.673	1.26	2.99	7.86
1.01	2.42	2.79	7.39
1.21	2.74	2.59	7.13
1.41	3.12	2.39	6.40
1.60	3.61	2.20	6.05
1.80	4.15	2.00	5.53
2.00	4.70	1.80	5.19
2.20	5.21	1.60	4.61
2.40	5.66	1.40	4.19
2.59	6.11	1.20	3.76
2.79	6.57	1.00	3.29
2.99	6.70	0.669	2.48
3.19	7.18	0.332	1.92
3.39	8.13	- 0.004	1.24



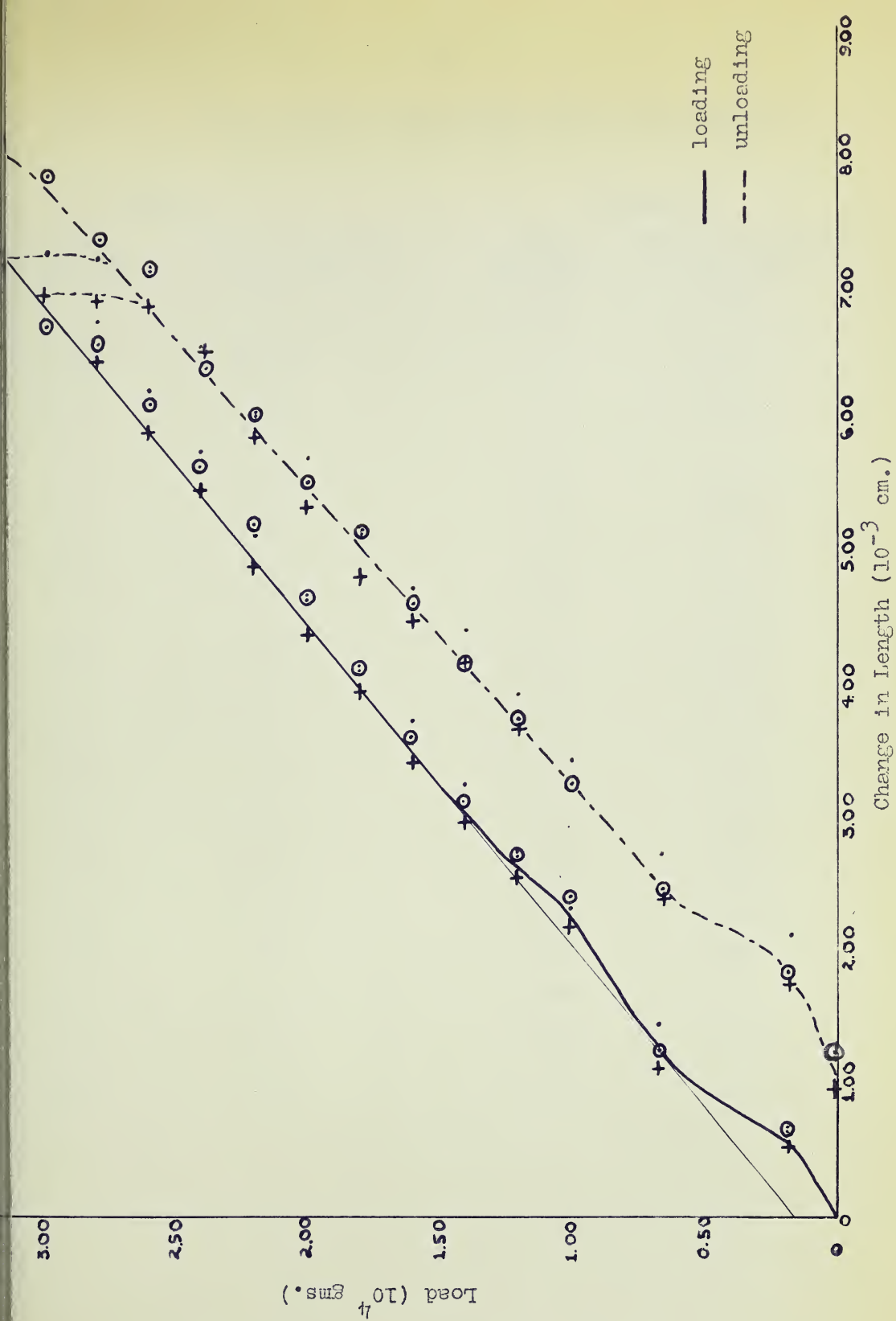


Fig. VIII. Brass Crystal Annealed at 500° C. and quenched from 400° C.  
Temperature 22.4° C.



TABLE IX. Brass Crystal Annealed at 500°C. and Quenched  
from 400°C. Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	3.99	8.90
0.338	0.299	3.79	8.85
0.674	1.18	3.59	8.30
1.01	2.16	3.39	7.75
1.21	2.58	3.19	7.26
1.41	3.08	2.99	6.83
1.60	3.57	2.79	6.32
1.80	4.04	2.60	5.80
2.00	4.48	2.40	5.25
2.20	5.02	2.20	4.91
2.40	5.42	2.00	—
2.60	5.78	1.80	4.27
2.79	6.26	1.60	3.80
2.99	6.66	1.40	3.42
3.19	7.11	1.21	2.76
3.39	7.56	1.01	2.24
3.59	8.10	0.674	1.22
3.79	8.47	0.336	0.960
3.99	8.90	- 0.002	0.512



TABLE IX. cont'd. Brass Crystal Annealed at 500°C. and Quenched from 400°C. Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	3.98	9.00
0.339	0.406	3.79	8.93
0.674	1.13	3.59	8.45
1.01	2.07	3.39	8.00
1.21	2.42	3.19	7.54
1.41	2.84	2.99	6.75
1.60	3.31	2.79	6.35
1.80	3.80	2.60	5.94
2.00	4.27	2.40	5.47
2.20	4.80	2.20	5.08
2.40	5.21	2.00	4.48
2.60	5.81	1.80	4.06
2.79	6.20	1.60	3.48
2.99	6.64	1.41	3.06
3.19	7.13	1.21	2.56
3.39	7.65	1.01	2.16
3.59	8.10	0.672	1.61
3.79	8.58	0.334	1.37
3.98	9.00	0	0



TABLE IX. cont'd. Brass Crystal Annealed at 500°C. and Quenched from 400°C. Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	3.98	9.35
0.338	0.299	3.78	9.29
0.674	1.09	3.59	8.90
1.01	1.92	3.39	8.36
1.21	2.33	3.19	7.88
1.41	2.82	2.99	7.54
1.60	3.31	2.79	7.15
1.80	3.86	2.59	6.47
2.00	4.33	2.40	6.04
2.20	4.92	2.20	5.51
2.40	5.42	2.00	5.01
2.60	5.85	1.80	4.70
2.79	6.39	1.60	4.03
2.99	6.90	1.40	3.50
3.19	7.45	1.21	3.23
3.39	7.98	1.01	2.58
3.59	8.43	0.670	2.12
3.79	8.93	0.333	1.73
3.98	9.35	- 0.003	0.960



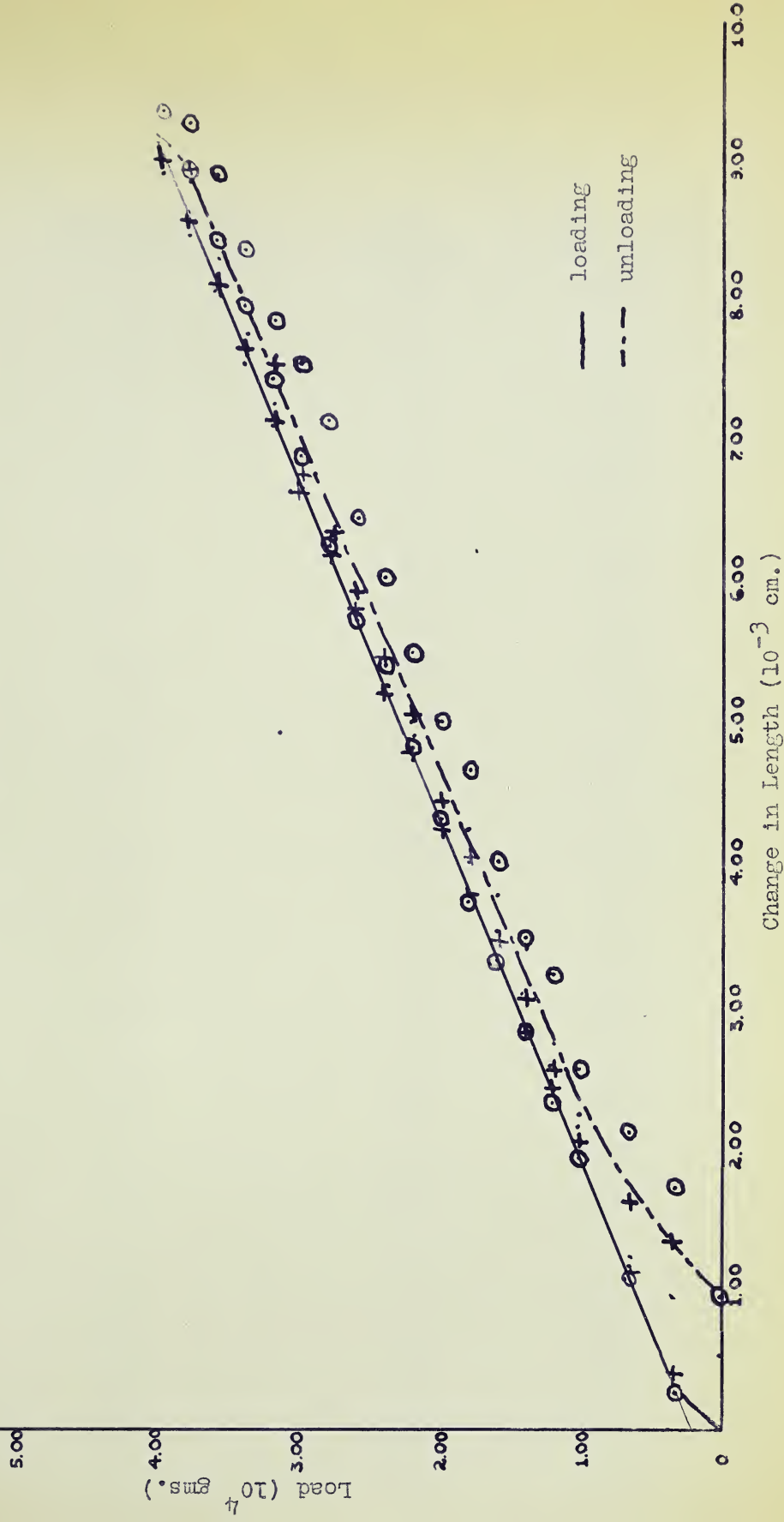


Fig. IX. Brass Crystal Annealed at  $500^{\circ}$  C. and quenched from  $400^{\circ}$  C.  
Liquid Nitrogen Temperature



TABLE X. Brass Crystal Heated at 575°C. and Quenched.  
Temperature 22.4°C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	3.00	5.66
0.337	0.555	2.80	5.62
0.673	1.30	2.60	5.57
1.01	2.20	2.40	5.32
1.21	2.54	2.20	4.91
1.41	2.93	2.00	4.57
1.61	3.20	1.80	4.48
1.80	3.46	1.60	4.18
2.00	3.70	1.40	3.78
2.20	4.00	1.20	3.36
2.40	4.31	1.01	2.80
2.60	4.71	0.672	1.73
2.80	5.14	0.336	0.918
3.00	5.66	0	0
0	0	3.00	5.70
0.337	0.512	2.80	5.70
0.673	1.30	2.60	5.66
1.01	2.18	2.40	5.50
1.21	2.42	2.20	5.21
1.41	2.65	2.00	5.00
1.61	2.91	1.80	—
1.80	3.27	1.60	4.35
2.00	3.66	1.40	4.04
2.20	4.06	1.20	3.38
2.40	4.48	1.01	2.82
2.60	4.93	0.671	1.84
2.80	5.34	0.336	0.960
3.00	5.70	0	0.085



TABLE X. cont'd. Brass Crystal Heated at 575°C. and Quenched.  
Temperature 22.4°C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	4.58	9.35
0.337	0.555	4.38	9.33
0.674	1.20	4.18	9.22
1.01	2.18	3.98	8.97
1.21	2.35	3.79	8.71
1.41	2.65	3.59	8.25
1.61	2.93	3.39	7.73
1.80	3.16	3.19	7.19
2.00	3.67	2.99	6.84
2.20	4.03	2.79	6.57
2.40	4.48	—	—
2.60	4.84	—	—
2.80	5.42	—	—
3.00	5.72	—	—
3.19	6.23	—	—
3.39	6.57	—	—
3.59	7.02	1.40	4.00
3.79	7.56	1.20	3.57
3.99	7.96	1.01	3.14
4.19	8.38	0.671	2.09
4.39	8.84	0.334	1.45
4.58	9.35	- 0.001	0.342



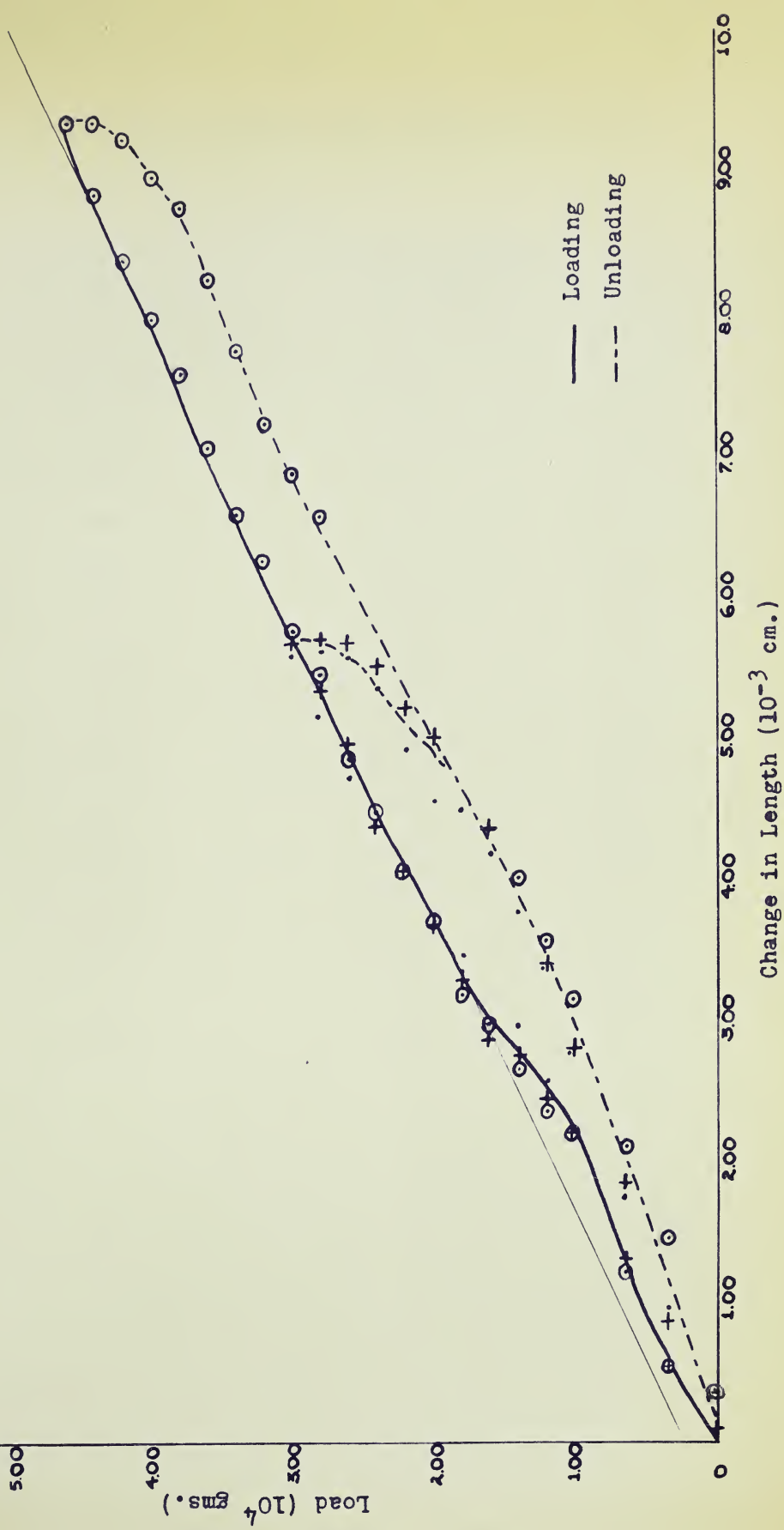


Fig. X. Brass Crystal Heated at  $575^{\circ}$  C. and Quenched. Temperature  $22.4^{\circ}$  C.



TABLE XI. Brass Crystal Heated at 575°C. and Quenched.  
Liquid Nitrogen Temperature.

<u>Loading</u>	
<u>Load</u> <u>10<sup>4</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0
0.338	0.342
0.673	1.32
1.01	2.48
1.40	3.89
1.60	4.48
1.80	4.82
2.00	5.15
2.20	5.51
2.40	5.98
2.59	6.43
2.79	6.92
2.99	7.43
3.19	7.88
3.39	8.33
3.59	8.88



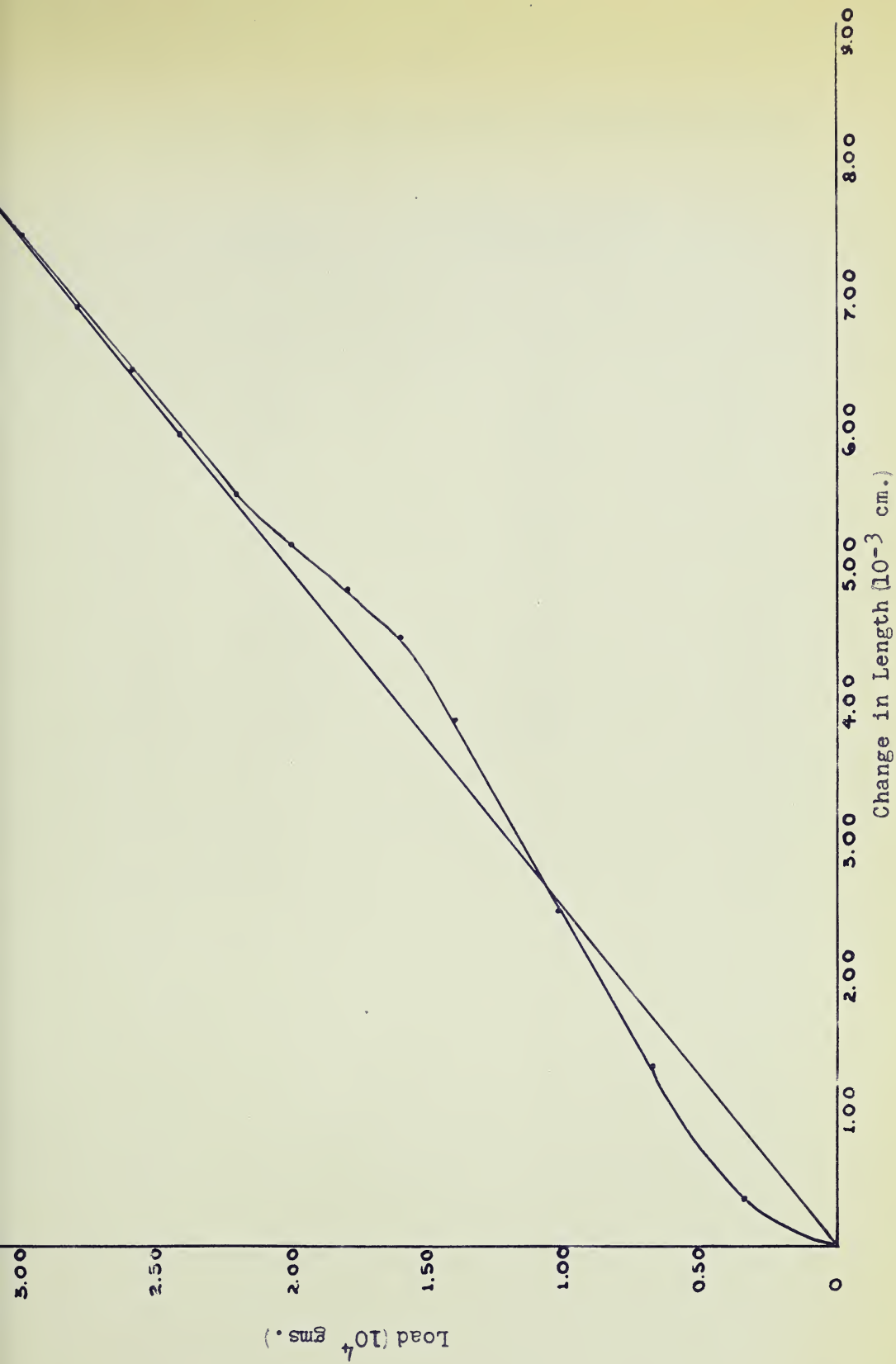


Fig. XI. Brass Crystal Heated at  $575^{\circ}$  C. and Quenched.  
Liquid Nitrogen Temperature.



TABLE XII. Copper Crystal as Received. Temperature 27.9°C.

<u>Load</u> <u><math>10^3</math> gms.</u>	<u>Change in Length</u> <u><math>10^{-3}</math> cm.</u>
0	0
1.00	0.063
1.99	0.214
2.98	0.468
3.97	0.790
4.95	1.07
5.94	1.35
6.94	1.65
7.93	2.05
8.92	2.48
9.82	5.18



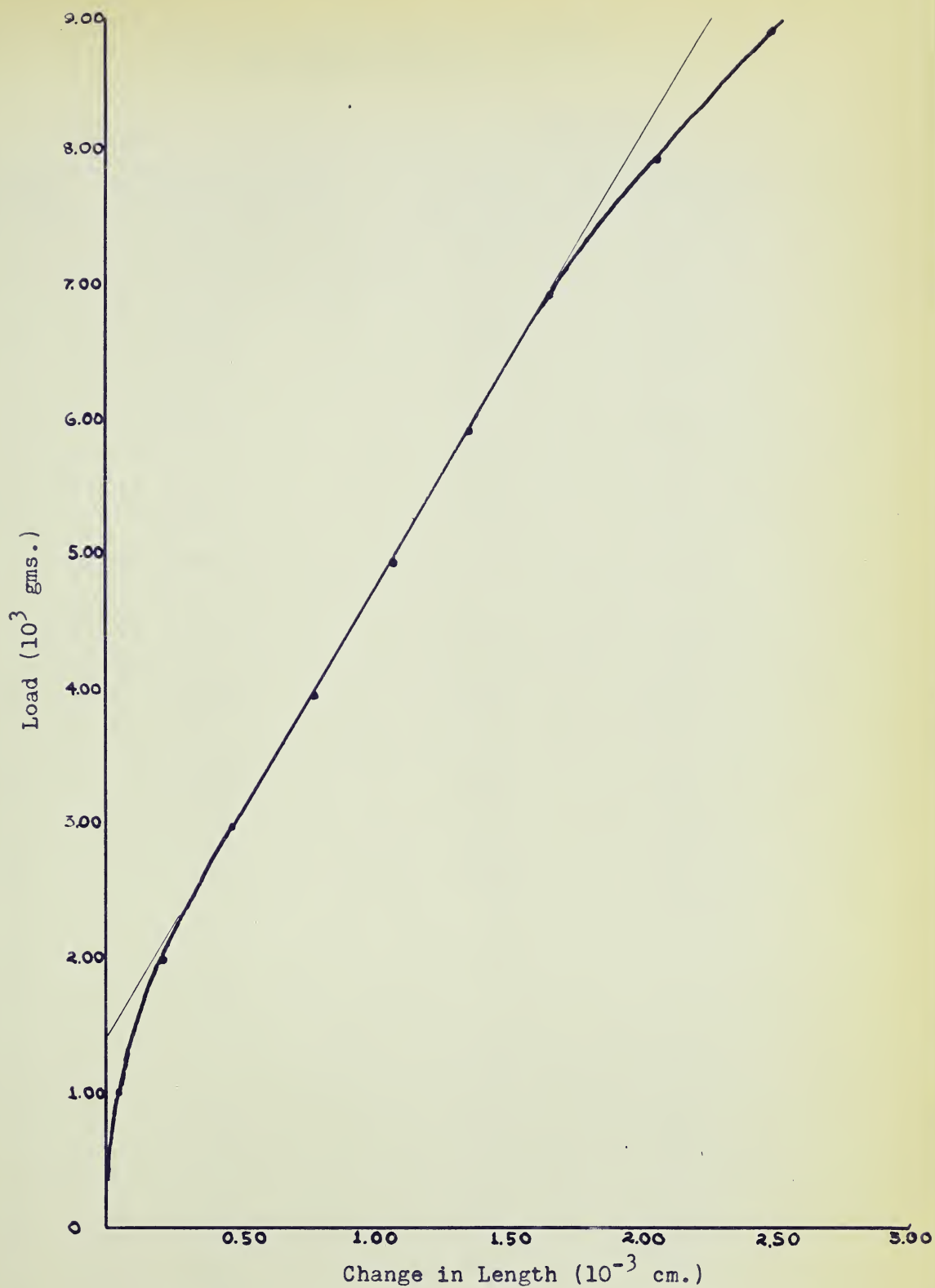
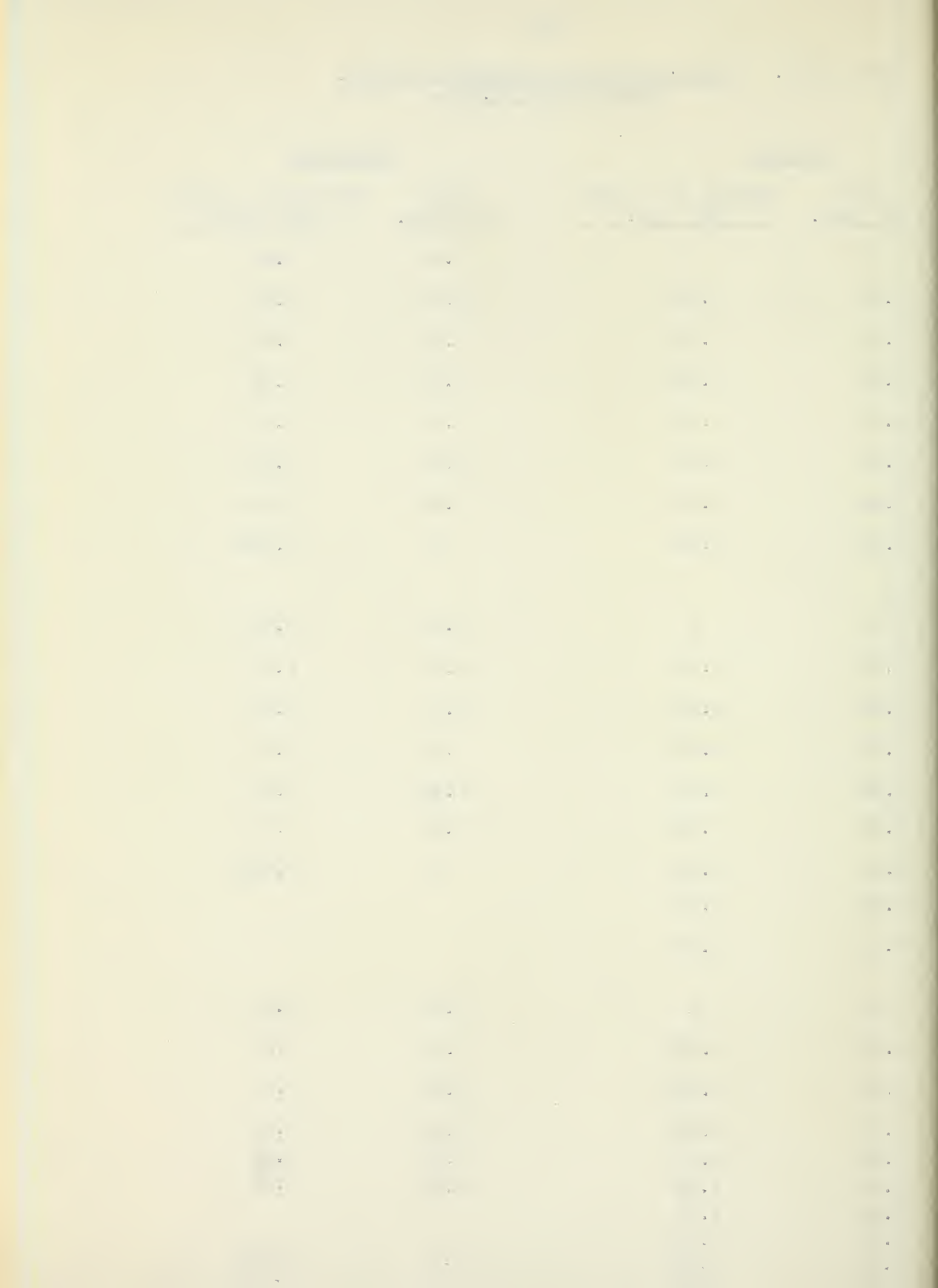


Fig. XII. Copper as Received. Temperature 27.9° C.



Table XIII. Copper Crystal Annealed at 195°C.  
Temperature 28.1°C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	7.43	2.05
1.99	0.256	6.93	2.05
2.98	0.512	5.93	2.05
3.97	0.832	4.93	1.97
4.96	1.15	3.94	1.75
5.95	1.47	2.95	1.52
6.94	1.81	1.96	1.24
7.43	2.05	0	0.597
0	0	7.43	1.90
1.99	0.171	6.93	1.90
2.98	0.470	6.43	1.90
3.97	0.769	5.94	1.82
4.96	1.07	4.94	1.60
5.95	1.39	3.95	1.35
6.45	1.56	0	0.620
6.94	1.75		
7.43	1.90		
0	0	7.93	2.07
1.99	0.256	7.43	2.07
2.98	0.555	6.93	2.07
3.97	0.832	6.43	2.07
4.96	1.11	5.93	1.99
5.95	1.41	4.94	1.86
6.45	1.56		
6.94	1.73		
7.43	1.88	1.96	1.28
7.93	2.07	0	0.598



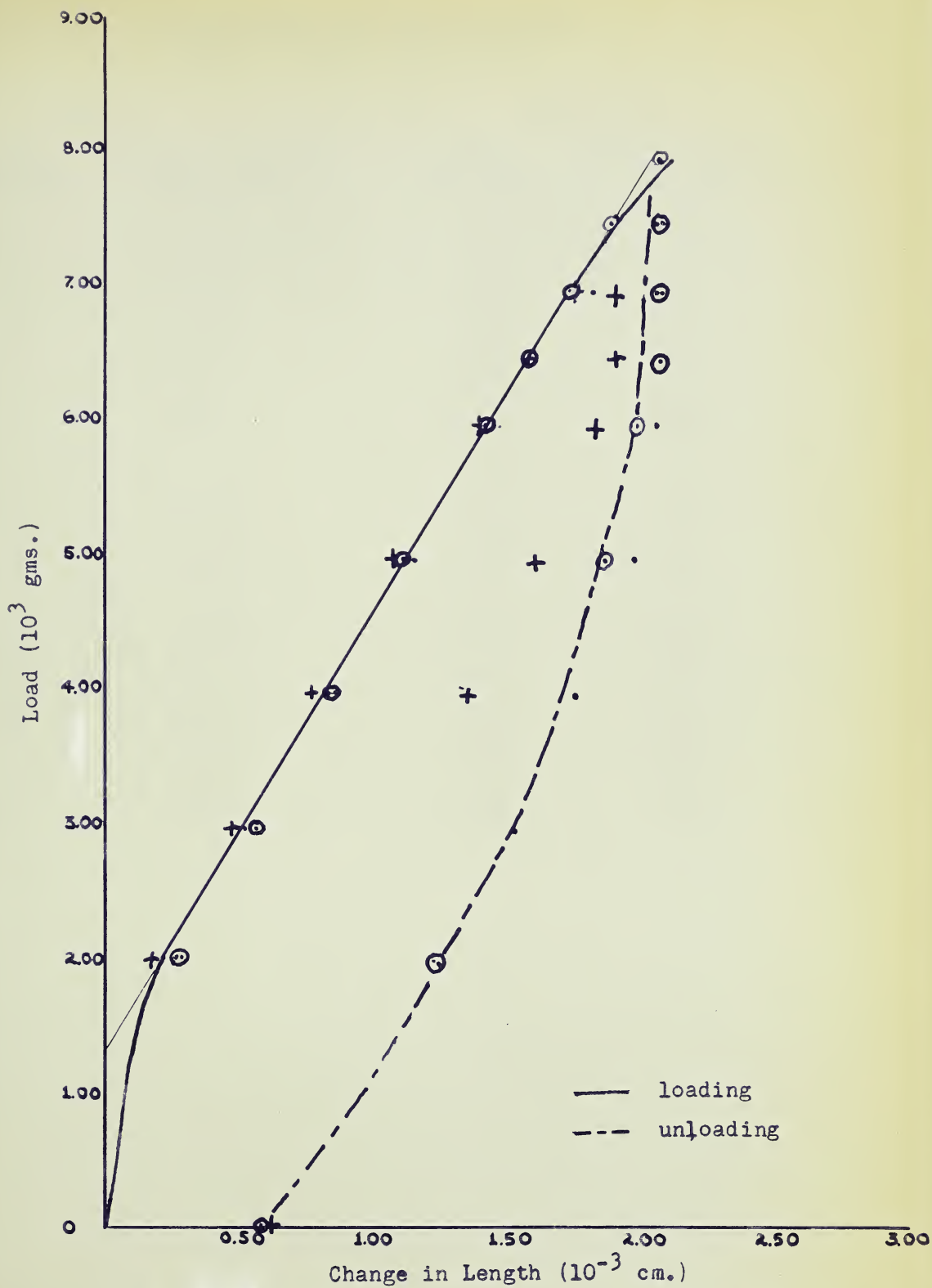


Fig. XIII. Copper Crystal Annealed at  $195^{\circ}$  C.  
Temperature  $28.1^{\circ}$  C.



TABLE XIV. Copper Crystal Annealed at 195°C.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0.000	8.94	1.62
2.00	0.021	7.94	1.62
3.99	0.235	5.94	1.62
5.97	0.747	3.94	1.62
7.96	1.24	2.97	0.961
8.94	1.62	-0.02	0.470
0.00	0.000	10.9	2.31
2.00	0.000	9.92	2.31
3.99	0.214	8.92	2.31
5.98	0.662	7.92	2.31
7.95	1.28	5.92	2.16
8.94	1.60	3.94	1.75
9.93	1.92	1.96	1.09
10.9	2.31	-0.02	.491

1880		1881	
Jan 1	1000	Jan 1	1000
Feb 1	1000	Feb 1	1000
Mar 1	1000	Mar 1	1000
Apr 1	1000	Apr 1	1000
May 1	1000	May 1	1000
Jun 1	1000	Jun 1	1000
Jul 1	1000	Jul 1	1000
Aug 1	1000	Aug 1	1000
Sep 1	1000	Sep 1	1000
Oct 1	1000	Oct 1	1000
Nov 1	1000	Nov 1	1000
Dec 1	1000	Dec 1	1000
Jan 2	1000	Jan 2	1000
Feb 2	1000	Feb 2	1000
Mar 2	1000	Mar 2	1000
Apr 2	1000	Apr 2	1000
May 2	1000	May 2	1000
Jun 2	1000	Jun 2	1000
Jul 2	1000	Jul 2	1000
Aug 2	1000	Aug 2	1000
Sep 2	1000	Sep 2	1000
Oct 2	1000	Oct 2	1000
Nov 2	1000	Nov 2	1000
Dec 2	1000	Dec 2	1000

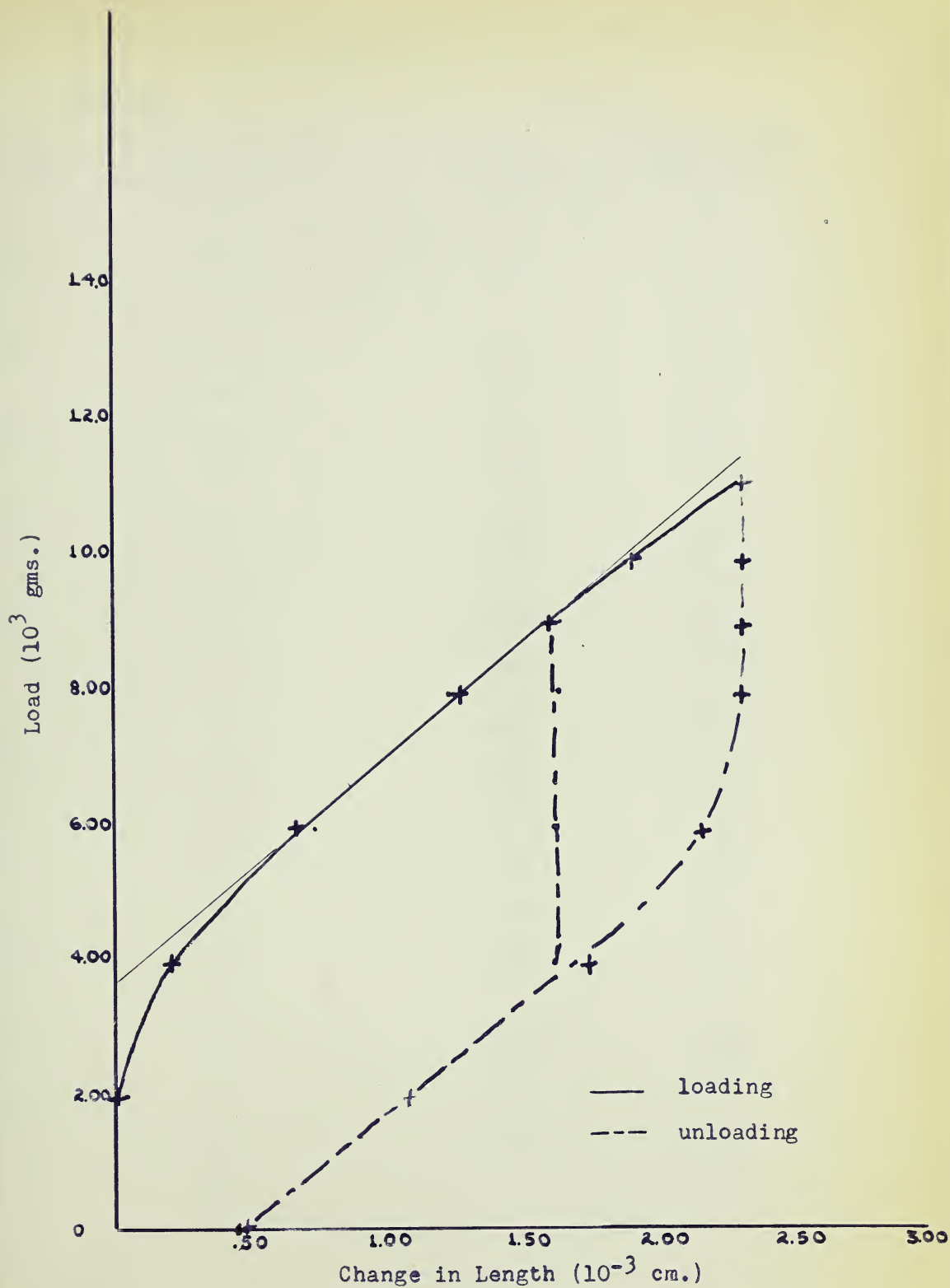


Fig. XIV. Copper Crystal Annealed at  $195^{\circ}$  C.  
Liquid Nitrogen Temperature



TABLE XV. Copper Crystal Annealed at 500°C. Temperature 22.5°C.

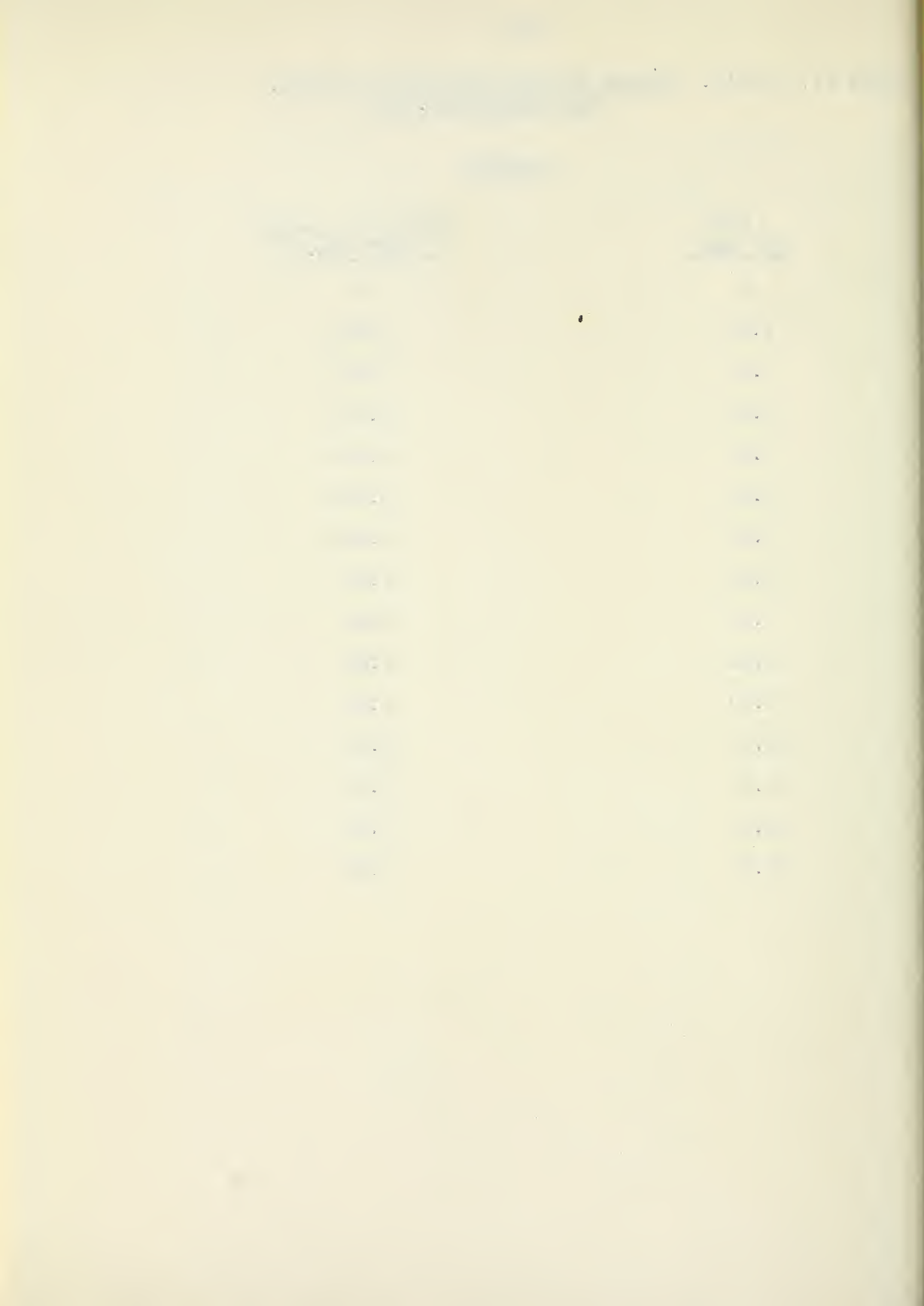
<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	9.93	2.05
1.00	0.000	8.93	2.05
2.00	0.000	7.93	2.05
2.99	0.171	6.93	2.05
3.99	0.385	5.93	1.96
4.98	0.640	4.94	1.80
5.97	0.960	3.95	1.54
6.96	1.24	2.96	1.28
7.95	1.50	1.97	0.980
8.94	1.75	0.980	0.620
9.93	2.05	- 0.010	0.300
0	0	9.93	1.92
1.00	0.000	8.93	1.92
2.00	0.022	7.93	1.92
2.99	0.171	6.93	1.92
3.99	0.341	5.94	1.84
4.98	0.597	4.94	1.62
5.97	0.853	3.96	1.26
6.96	1.13	2.97	0.982
7.95	1.39	1.97	0.748
8.94	1.67	0.985	0.427
9.93	1.92	0	0.128



TABLE XV. cont'd. Copper Crystal Annealed at 500°C.  
Temperature 22.5°C.

Loading

<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0
1.00	0.000
2.00	0.000
2.99	0.171
3.99	0.385
4.98	0.620
5.97	0.873
6.96	1.18
7.95	1.43
8.94	1.67
9.93	1.94
10.9	2.26
11.9	2.63
12.9	3.05
13.9	3.60



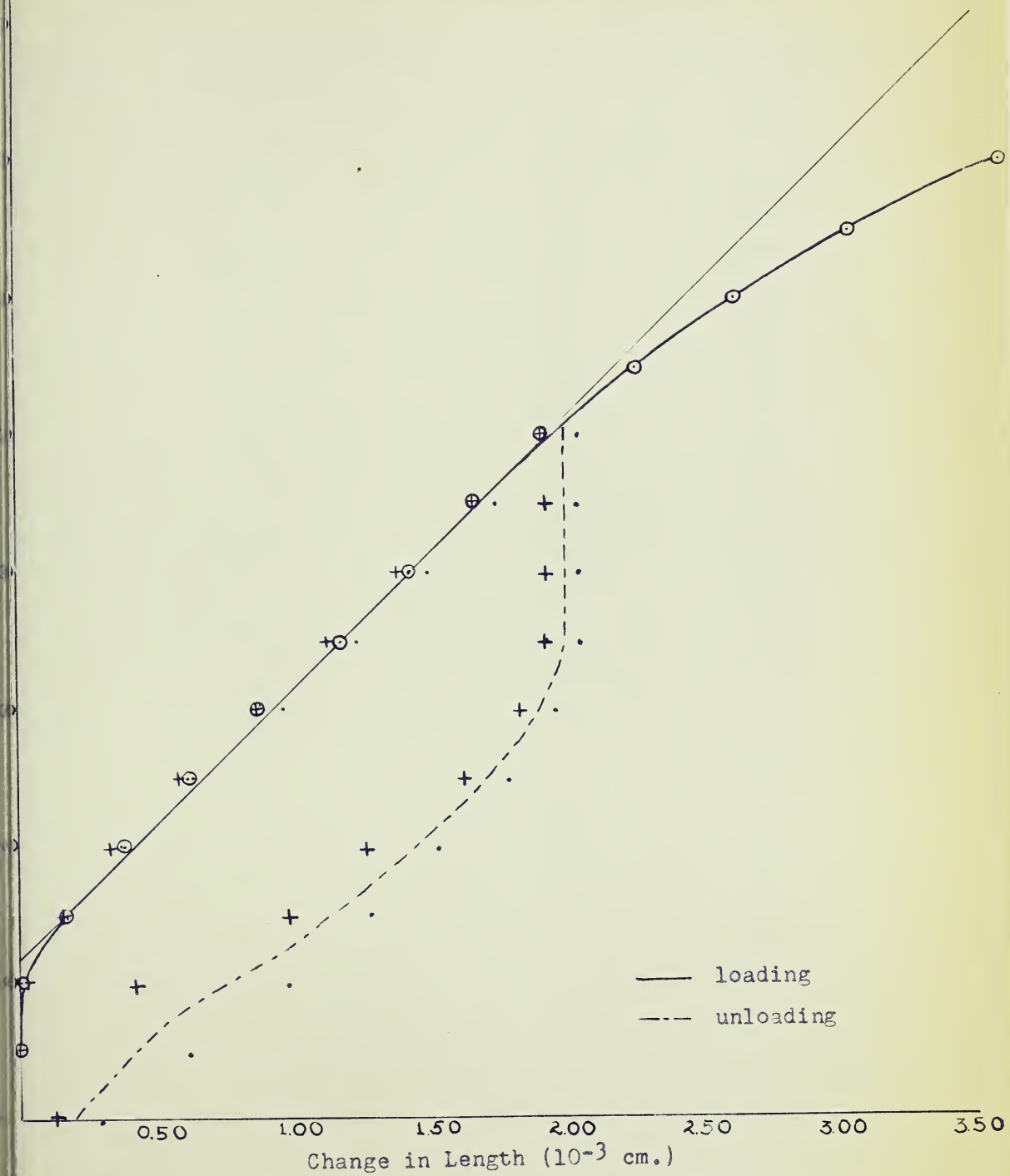


Fig. XV. Copper Crystal Annealed at  $500^{\circ}$  C.  
Temperature  $22.5^{\circ}$  C.



TABLE XVI. Copper Crystal Annealed at 500°C. Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	13.9	2.86
1.99	0.214	12.9	2.84
2.98	0.427	11.9	2.84
3.98	0.620	10.9	2.84
—	—	9.90	2.82
5.96	1.07	8.90	2.80
6.96	1.26	7.90	2.72
7.95	1.43	6.92	2.37
8.94	1.67	5.93	1.97
9.93	1.90	4.94	1.71
10.9	2.18	3.95	1.33
11.9	2.46	2.97	0.940
12.9	2.65	1.98	0.597
13.9	2.86	0	0.085



TABLE XVI. cont'd. Copper Crystal Annealed at 500°C. Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	13.9	3.25
1.99	0.235	12.9	3.23
2.98	0.470	11.9	3.23
3.97	0.770	10.9	3.23
4.96	1.03	9.89	3.21
5.95	1.26	8.89	3.21
6.95	1.49	7.89	3.18
7.94	1.79	6.90	2.92
8.93	2.07	5.91	2.52
9.92	2.29	4.92	2.14
10.9	2.54	3.94	1.77
11.9	2.84	2.95	1.56
12.9	3.04	1.96	1.24
13.9	3.25	-0.020	0.640



TABLE XVI. cont'd. Copper Crystal Annealed at 500°C. Liquid  
Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	17.8	4.89
1.99	0.320	16.8	4.89
2.98	0.640	15.8	4.89
3.97	0.960	14.8	4.89
4.96	1.24	13.8	4.89
5.95	1.47	12.8	4.89
6.94	1.84	11.8	4.87
7.93	2.07	10.8	4.85
8.92	2.35	9.83	4.78
9.91	2.58	8.84	4.67
10.9	2.84	7.85	4.16
--	--	6.86	3.91
12.9	3.40	5.88	3.53
13.9	3.74	4.89	3.06
14.9	3.96	3.91	2.82
15.9	4.25	2.92	2.35
16.8	4.52	1.93	2.07
17.8	4.89	-0.05	1.43



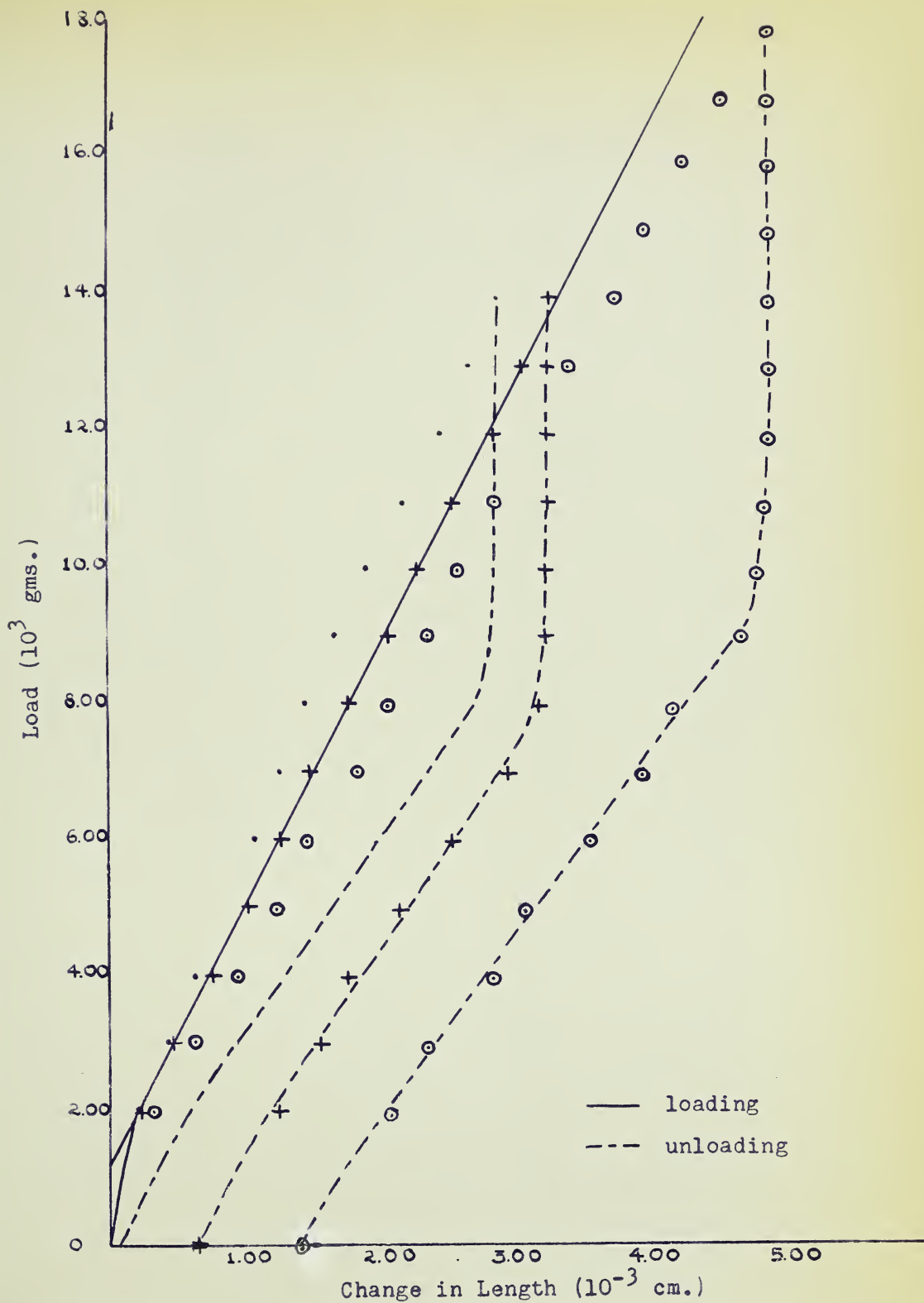


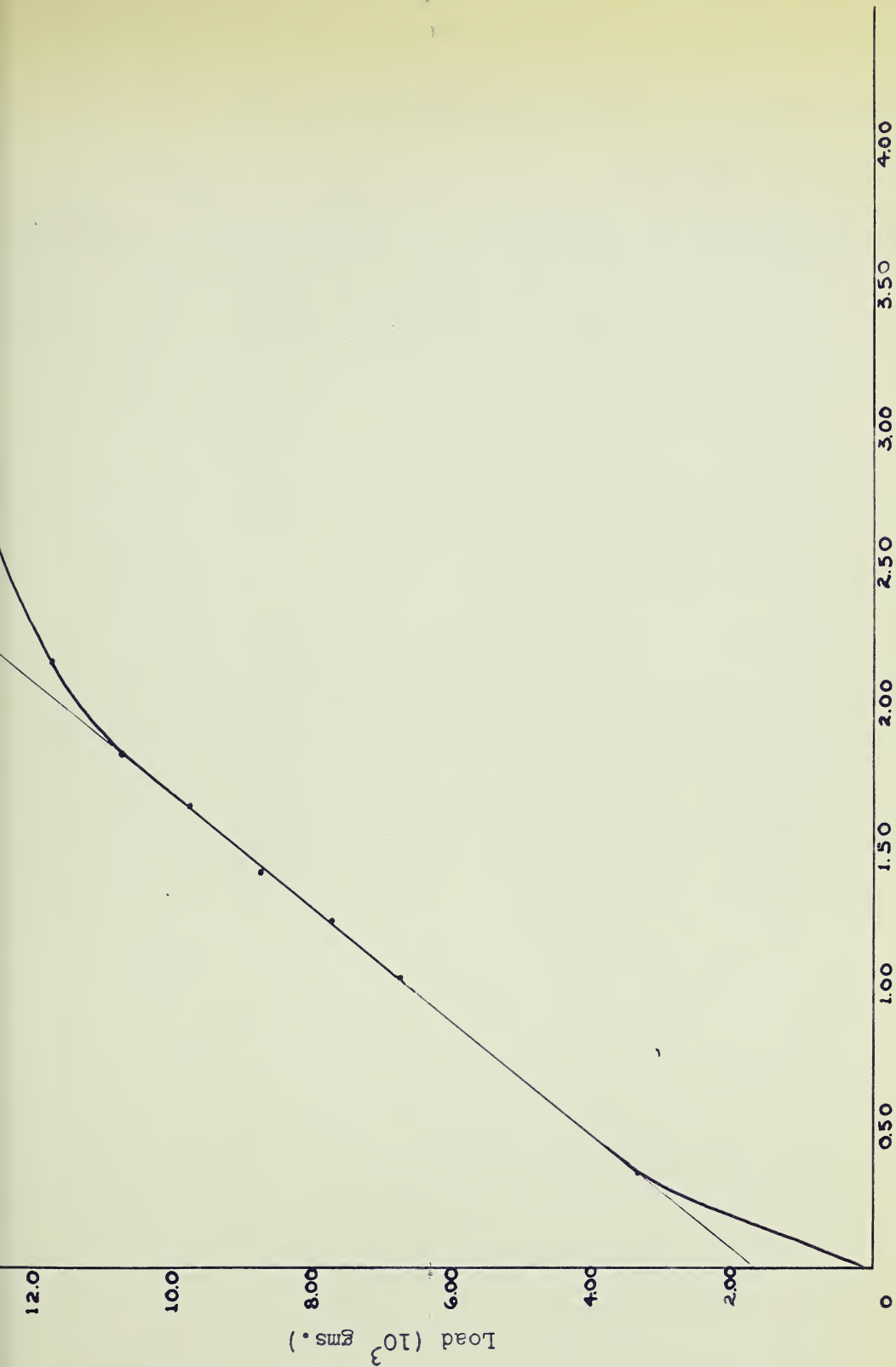
Fig. XVI. Copper Crystal Annealed at  $500^{\circ}$  C.  
Liquid Nitrogen Temperature



TABLE XVII. Zinc Crystal as Received. Temperature 28.1°C.

<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0
3.38	0.341
6.76	1.03
7.75	1.24
8.74	1.41
9.74	1.65
10.7	1.84
11.7	2.16
12.7	2.76





Change in Length ( $10^{-3}$  cm.)

Fig. XVII. Zinc Crystal as Received.  
Temperature  $28.10^{\circ}$  C.



TABLE XVIII. Zinc Crystal Annealed at 100°C. Temperature 25.0°C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	11.9	3.46
3.97	0.833	9.88	3.46
5.95	1.43	7.88	3.46
7.93	2.05	5.88	3.40
9.91	2.69	3.91	2.56
11.9	3.46	1.94	1.62
		-0.02	0.43
0	0	11.9	3.98
3.97	0.768	9.86	3.98
5.95	1.43	7.86	3.98
7.93	2.12	5.86	3.94
9.90	2.82	3.88	3.38
11.9	3.98	-0.04	1.20



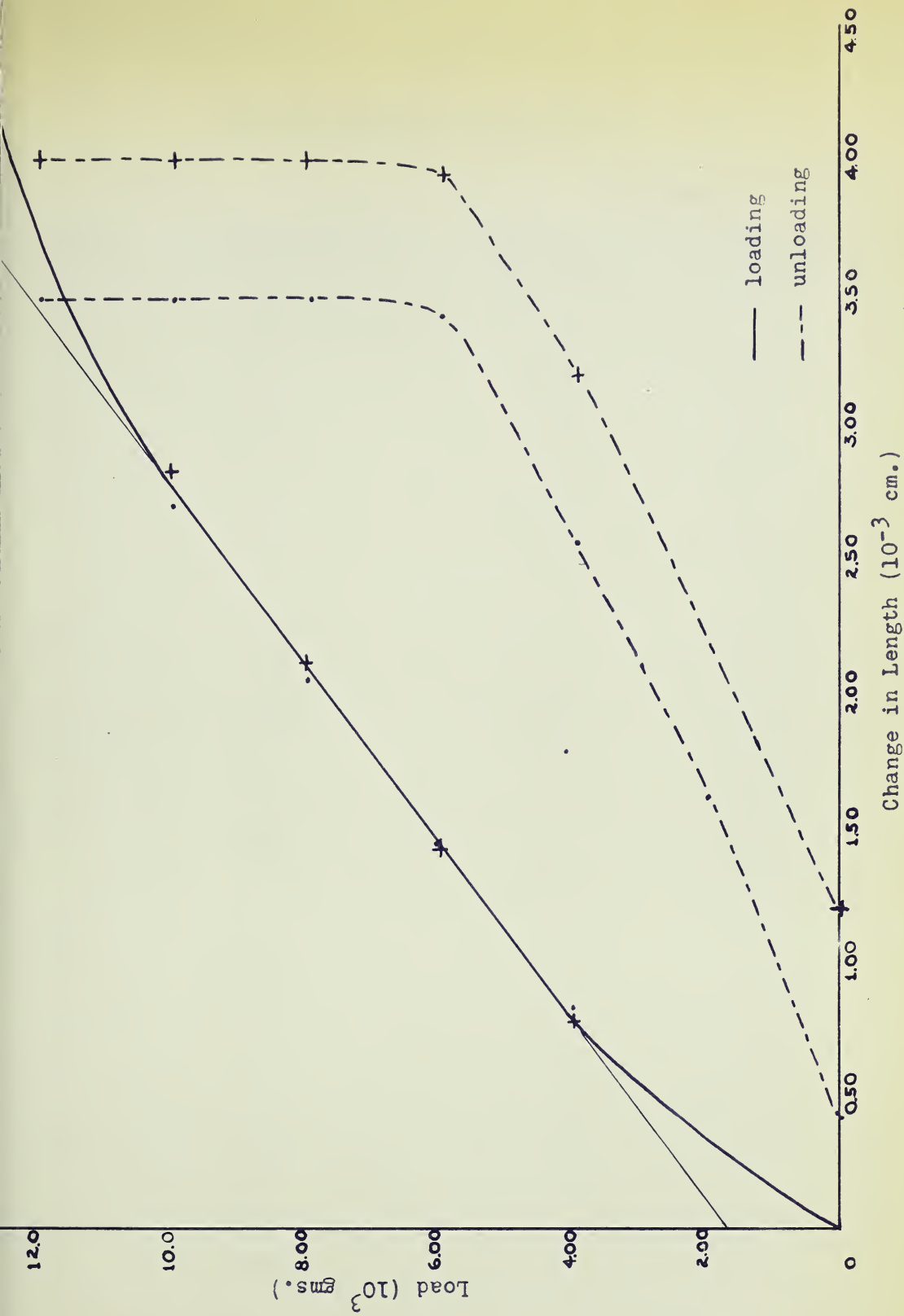
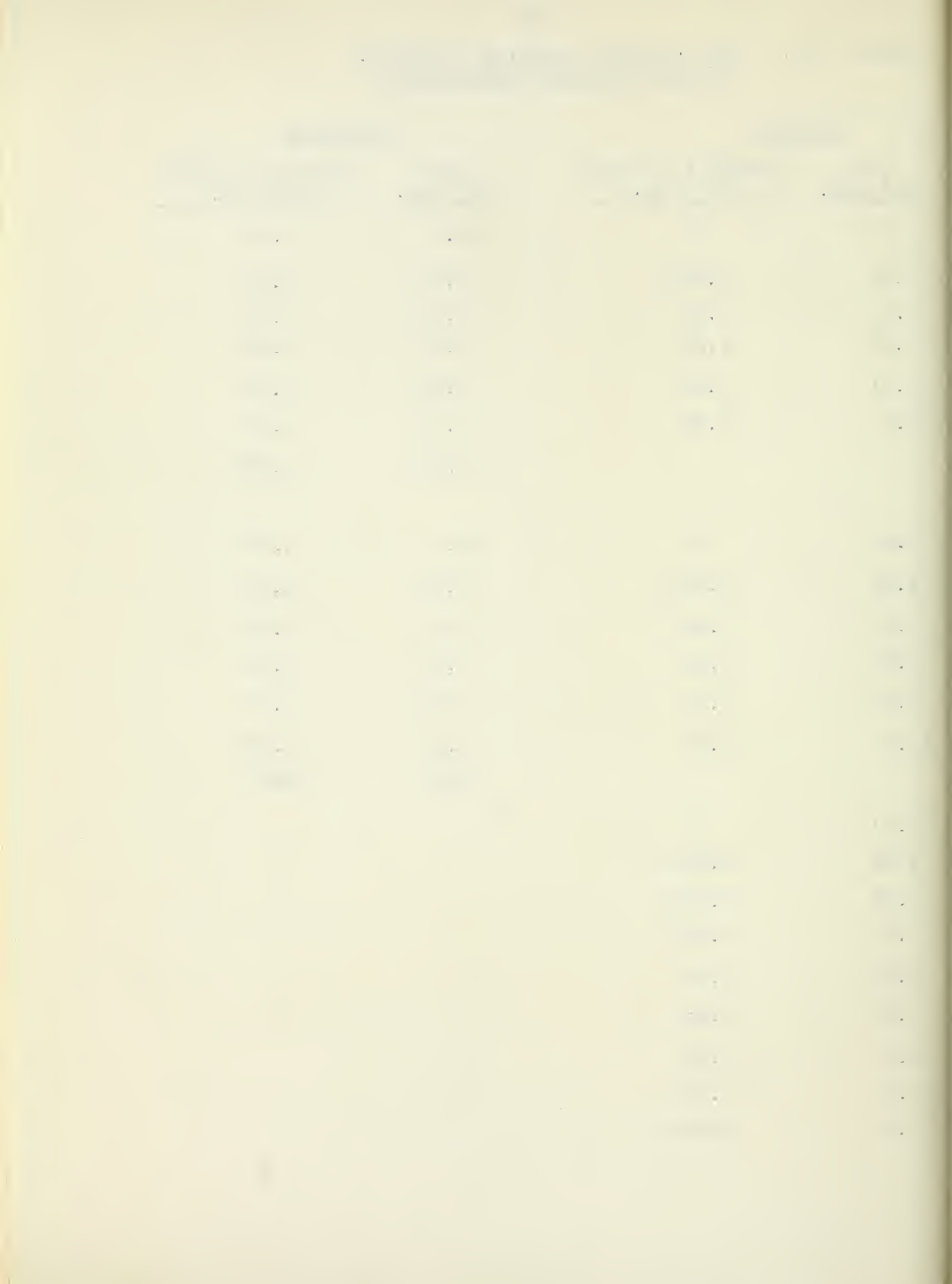


Fig. XVIII. Zinc Crystal Annealed at  $100^{\circ}$  C.  
Temperature  $25.00^{\circ}$  C.



TABLE XIX. Zinc Crystal Annealed at 100°C.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in length</u> <u>10<sup>-3</sup> cm.</u>
0	0	11.9	3.27
3.98	0.619	9.89	3.20
5.96	1.30	7.89	3.17
7.93	1.88	5.90	2.86
9.91	2.58	3.92	2.31
11.9	3.27	1.95	1.52
		-0.02	0.576
2.00	0	11.9	2.80
3.99	0.235	9.90	2.80
5.97	0.982	7.90	2.76
7.96	1.64	5.92	2.44
9.93	2.12	3.94	1.75
11.9	2.80	1.97	0.812
		0.00	0.00
1.00	0		
3.00	0.064		
4.98	0.597		
6.97	0.918		
8.95	1.52		
9.94	1.86		
10.9	2.26		
11.9	2.56		
13.0	broke		



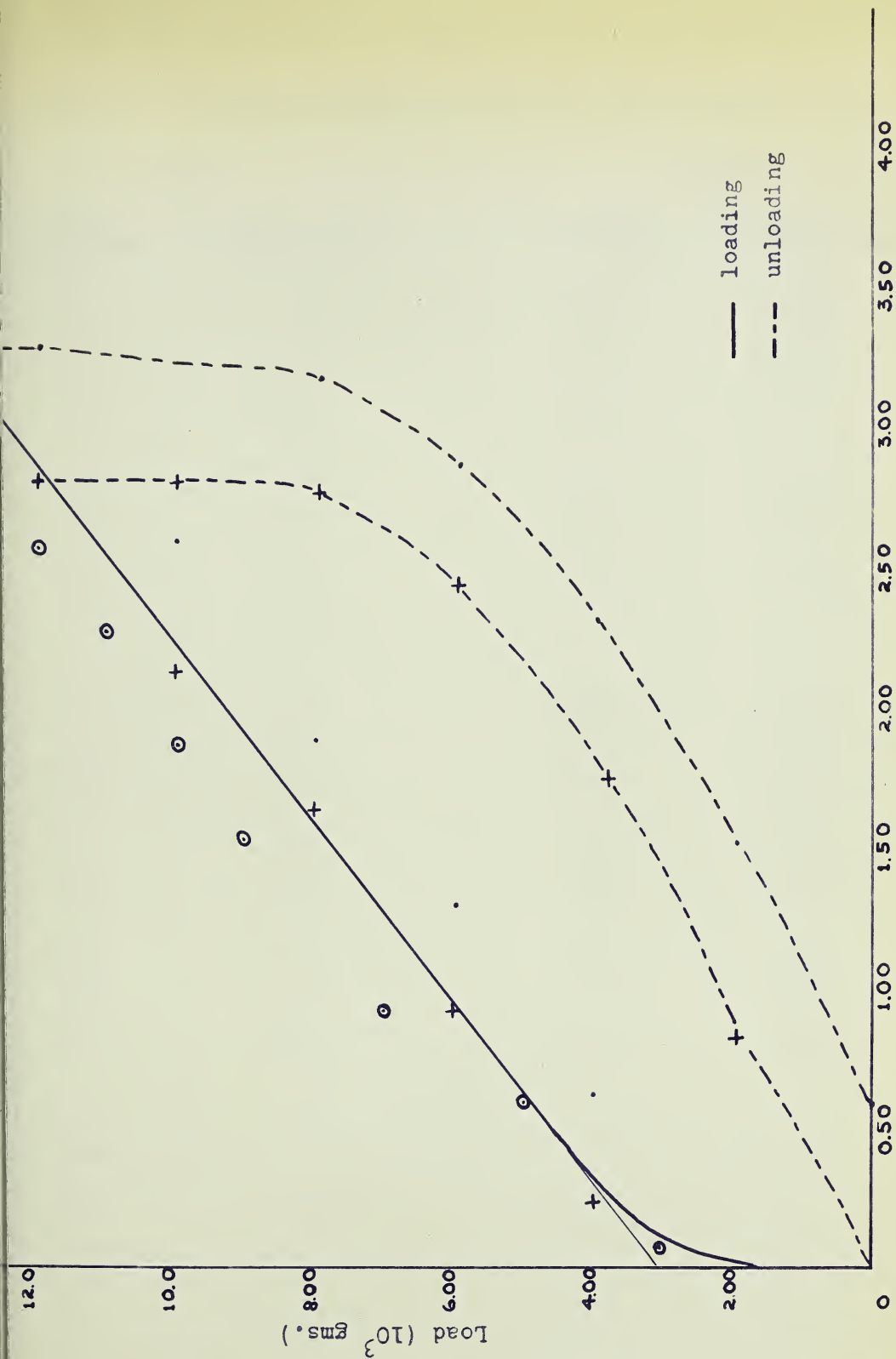


Fig. XIX. Zinc Crystal Annealed at  $100^{\circ}$  C.  
Liquid Nitrogen Temperature



TABLE XX. Aluminum Crystal as Received. Temperature 21.8°C.

<u>Loading</u>		<u>Unloading</u>	
<u>10<sup>3</sup> Load gms.</u>	<u>Change in Length 10<sup>-3</sup> cm.</u>	<u>10<sup>3</sup> Load gms.</u>	<u>Change in Length 10<sup>-3</sup> cm.</u>
0	0	6.87	3.66
0.992	0.214	5.87	3.66
1.97	0.768	4.87	3.66
2.96	1.28	3.88	3.55
3.94	1.88	2.90	2.95
4.92	2.44	1.92	2.22
5.90	3.03	0.953	1.39
6.87	3.66	-.015	.405
0	0	6.87	3.70
0.992	0.235	5.87	3.70
1.97	0.790	4.87	3.70
2.95	1.30	3.88	3.61
3.93	1.92	2.89	3.06
4.91	2.50	1.92	2.20
5.89	3.06	0.955	1.28
6.87	3.70	-0.010	0.257
0	0		
0.990	0.278		
1.97	0.790		
2.95	1.35		
3.93	1.95		
4.91	2.55		
5.89	3.07		
6.87	3.63		
7.85	4.29		
8.82	5.05		



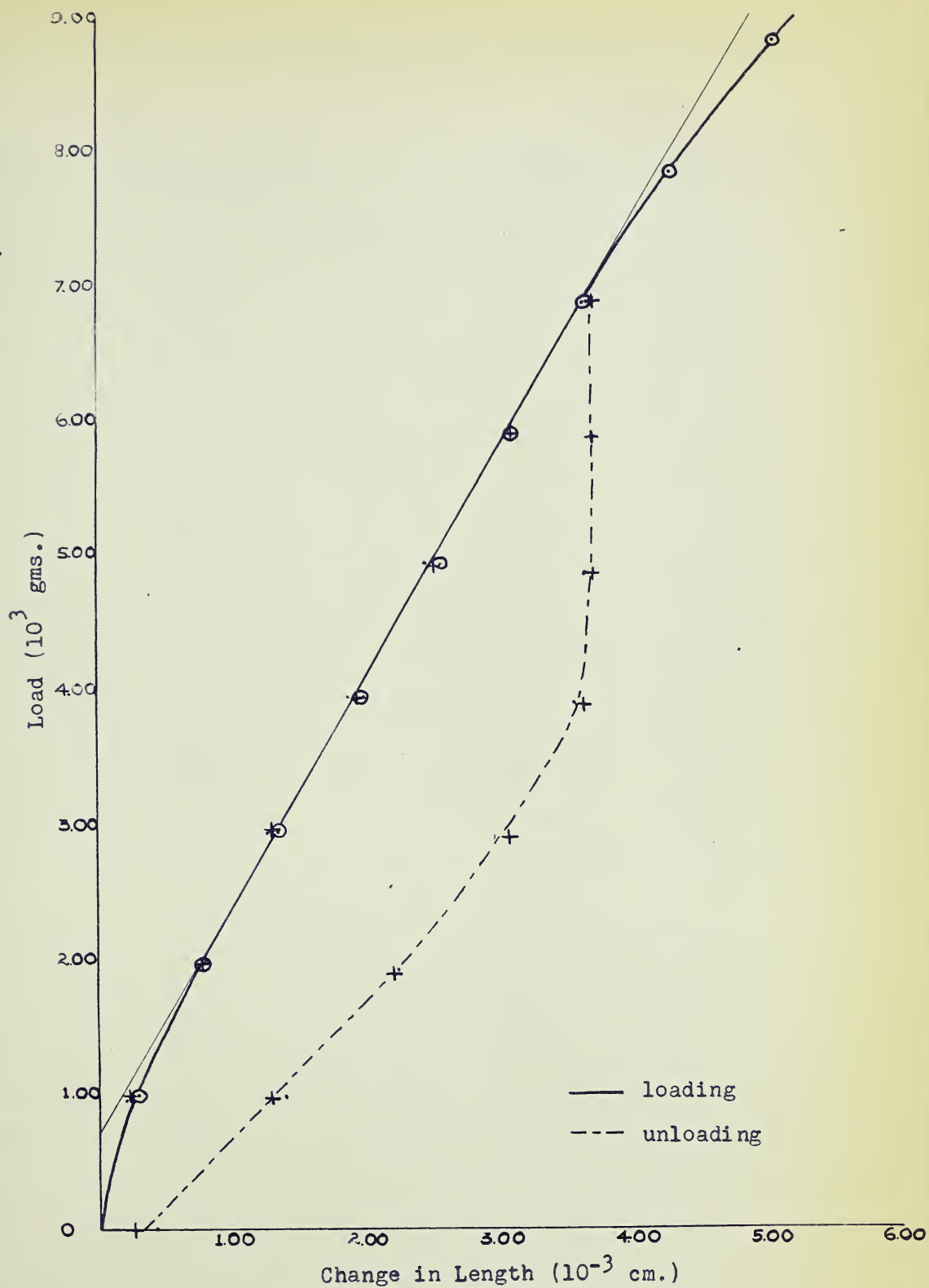


Fig. XX. Aluminum Crystal as Received.  
Temperature  $21.8^{\circ}$  C.



TABLE XXI. Aluminum Crystal as Received. Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u><math>10^3</math> gms.</u>	<u>Change in Length</u> <u><math>10^{-3}</math> cm.</u>	<u>Load</u> <u><math>10^3</math> gms.</u>	<u>Change in Length</u> <u><math>10^{-3}</math> cm.</u>
0	0	9.87	3.76
0.992	0.214	8.87	3.71
1.98	0.511	7.87	3.63
2.97	0.810	6.88	3.40
3.96	1.11	5.90	2.93
4.95	1.43	4.91	2.44
5.94	1.84	3.93	1.92
6.92	2.26	2.95	1.46
7.91	2.68	1.97	0.980
8.89	3.17	0.986	0.384
9.87	3.76	0	0
0	0	9.87	3.52
0.992	0.214	8.87	3.52
1.98	0.469	7.88	3.37
2.97	0.830	6.89	3.11
3.96	1.20	5.91	2.65
4.94	1.58	4.92	2.22
5.93	1.92	3.94	1.66
6.92	2.28	2.96	1.24
7.91	2.65	1.98	0.680
8.89	3.01	0.995	0.128
9.87	3.52	0	0

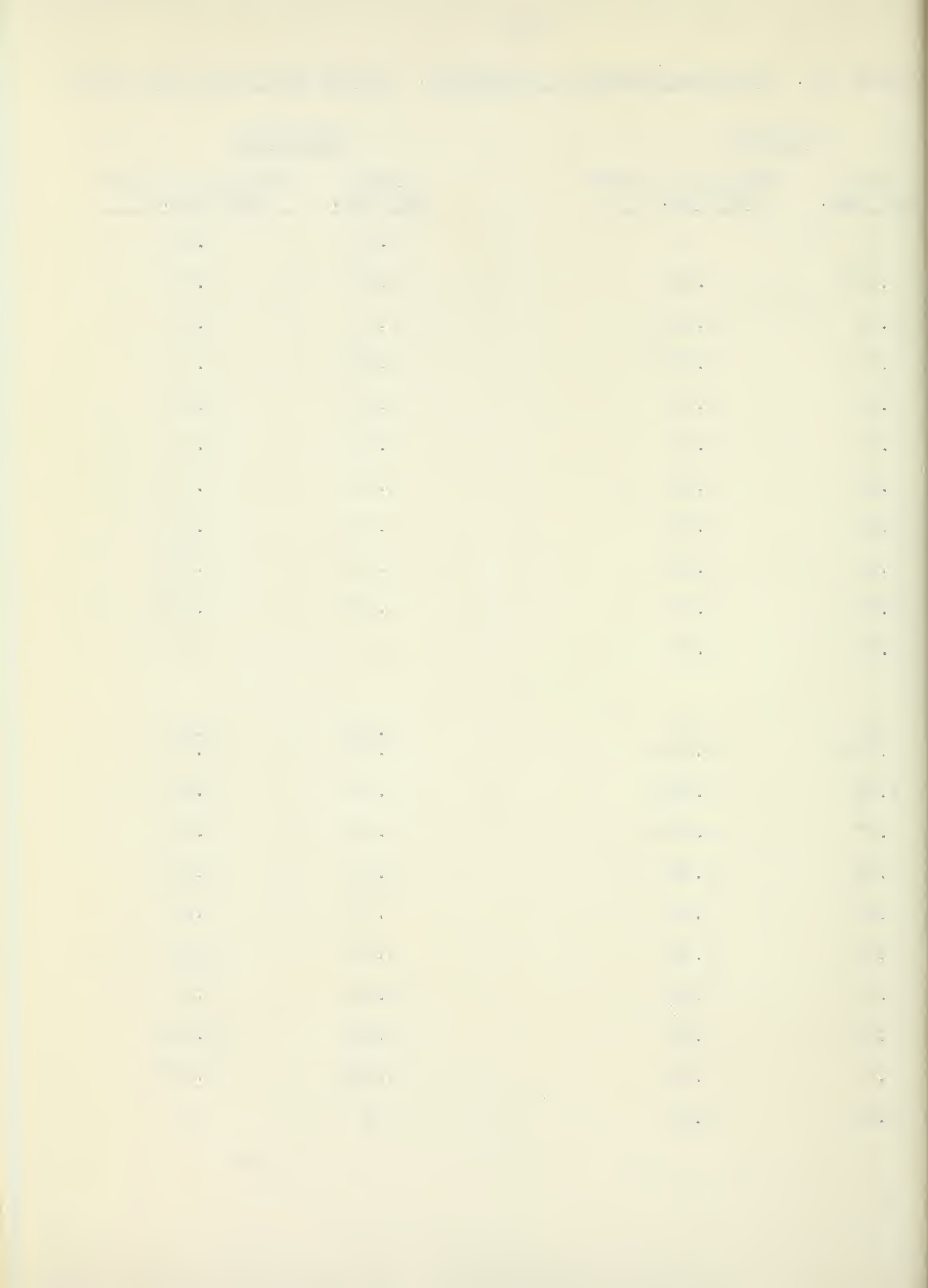


TABLE XXI. cont'd. Aluminum Crystal as Received.  
Liquid Nitrogen Temperature.

<u>Loading</u>	
<u>Load</u> <u>10<sup>5</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0
0.993	0.171
1.98	0.426
2.97	0.768
3.96	1.15
4.95	1.54
5.93	1.99
6.92	2.33
7.90	2.73
8.89	3.15
9.87	3.57
10.9	4.21



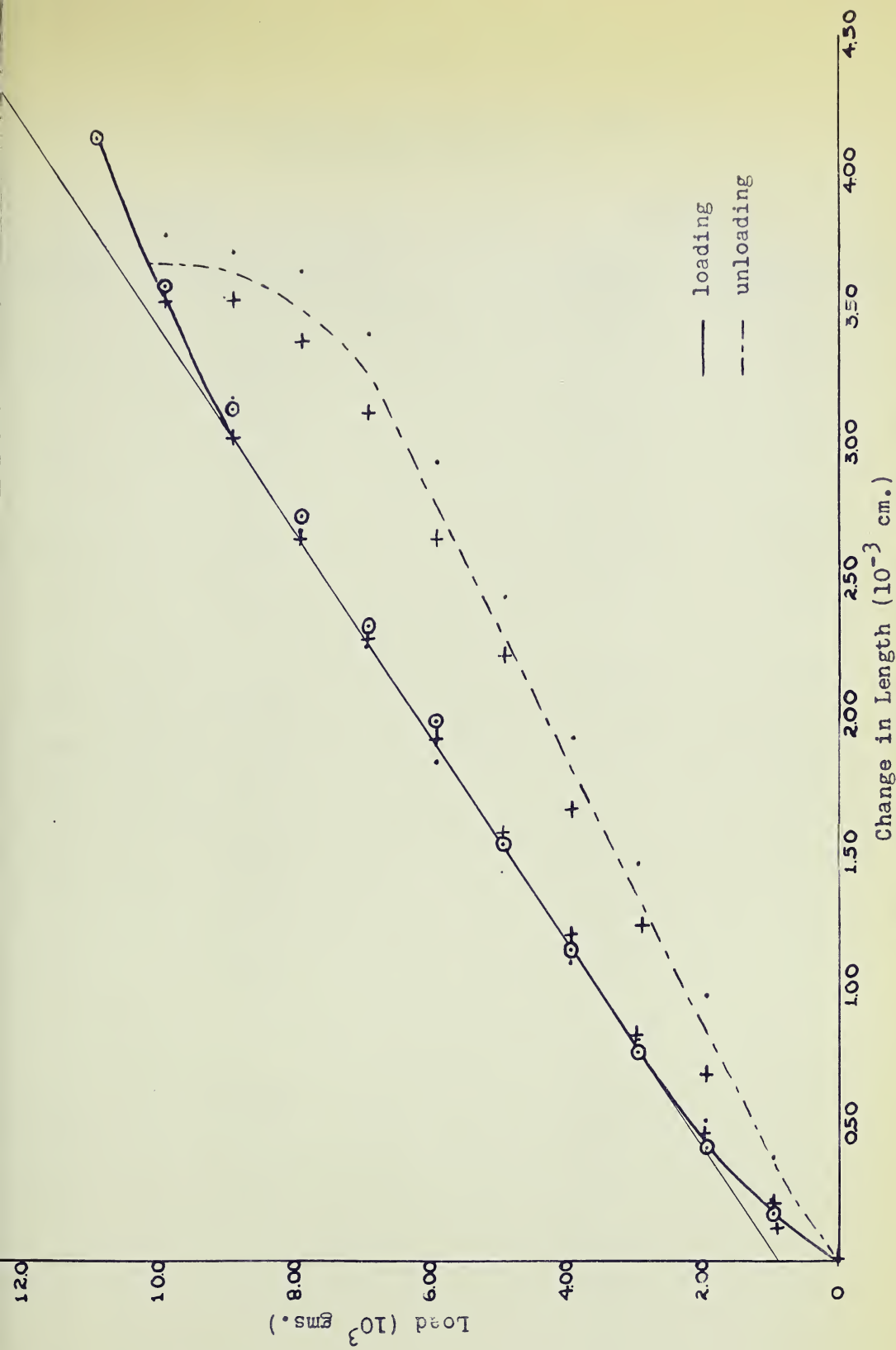


Fig. XXI. Aluminum Crystal as Received.  
Liquid Nitrogen Temperature.



TABLE XXII. Aluminum Crystal Annealed at 200°C.  
Temperature 22.5°C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	4.92	2.18
1.00	0.171	4.42	2.18
1.98	0.640	3.92	2.18
2.96	1.20	2.93	2.01
3.94	1.71	1.94	1.82
4.43	1.96	0.970	0.852
4.92	2.18	0	0.256
0	0	5.91	2.65
1.00	0.107	5.41	2.65
1.98	0.553	4.91	2.65
2.96	1.11	3.91	2.45
3.94	1.62	2.93	2.03
4.92	2.11	1.94	1.62
5.42	2.39	0.965	1.00
5.91	2.65	0	0.340
0	0	5.91	2.56
1.00	0.107	5.41	2.56
1.98	0.531	4.91	2.56
2.96	1.02	3.92	2.26
3.94	1.56	2.93	2.00
4.93	2.05	1.95	1.26
5.42	2.30	0.975	0.747
5.91	2.56	0	0.171



TABLE XXII. cont'd. Aluminum Crystal Annealed at 200°C.  
Temperature 22.5°C.

<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0
1.00	0.086
1.98	0.490
2.96	1.03
3.94	1.56
4.93	2.05
5.91	2.52
6.40	2.81
6.89	3.21



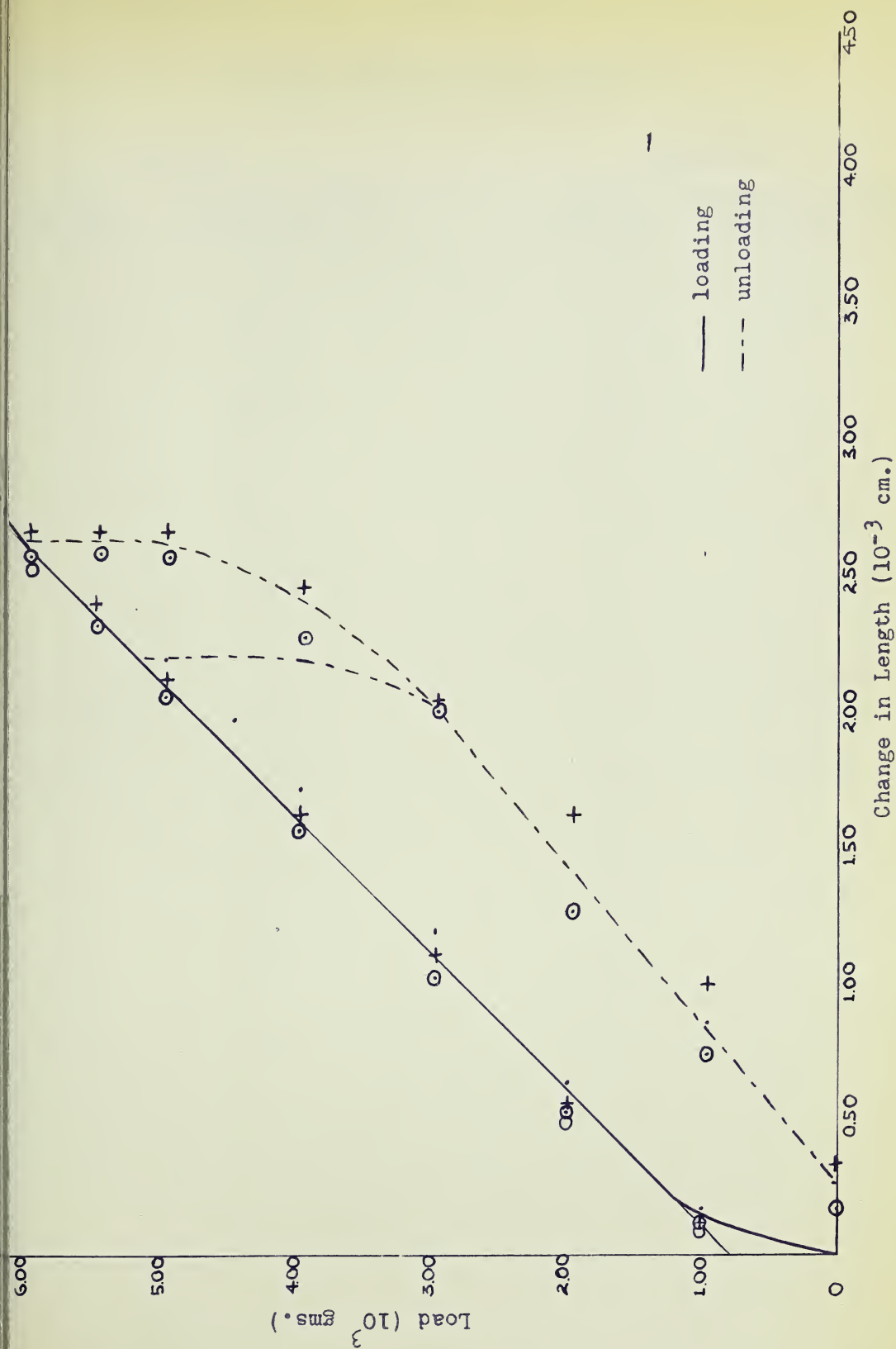


Fig. XXII. Aluminum Crystal Annealed at  $200^{\circ}$  C.  
Temperature  $22.50^{\circ}$  C.



TABLE XXIII. Aluminum Crystal Annealed at 200°C.  
Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gm.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	6.92	2.29
1.00	0.171	5.92	2.27
1.98	0.510	4.92	2.22
2.97	0.895	3.94	1.84
3.96	1.22	2.96	1.03
4.95	1.56	1.97	--
5.93	1.88	0.980	0.575
6.92	2.29	0	0
0	0	7.90	2.74
0.992	0.235	6.90	2.74
1.98	0.552	5.90	2.74
2.97	0.940	4.91	--
3.95	1.30	3.93	--
4.94	1.62	2.95	1.36
5.93	2.03	1.98	0.680
6.92	2.35	0.994	0.171
7.90	2.74	0	0



TABLE XXIII. cont'd. Aluminum Crystal Annealed at 200°C.  
Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	7.90	2.73
0.992	0.235	6.90	2.73
1.98	0.510	5.90	2.73
2.97	0.895	4.91	2.65
3.95	1.28	3.92	2.31
4.94	1.62	2.94	--
5.93	2.00	1.95	1.11
6.92	2.39	0.980	0.597
7.90	2.73	-.018	0.235
0	0		
0.992	0.213		
1.98	0.597		
2.97	0.980		
3.95	1.41		
4.94	1.79		
5.92	2.15		
6.91	2.55		
7.90	2.89		
8.88	3.41		
9.85	4.25		

ORIGINAL ARTICLES		DEPARTMENTS	
1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32
33	34	35	36
37	38	39	40
41	42	43	44
45	46	47	48
49	50	51	52
53	54	55	56
57	58	59	60
61	62	63	64
65	66	67	68
69	70	71	72
73	74	75	76
77	78	79	80
81	82	83	84
85	86	87	88
89	90	91	92
93	94	95	96
97	98	99	100

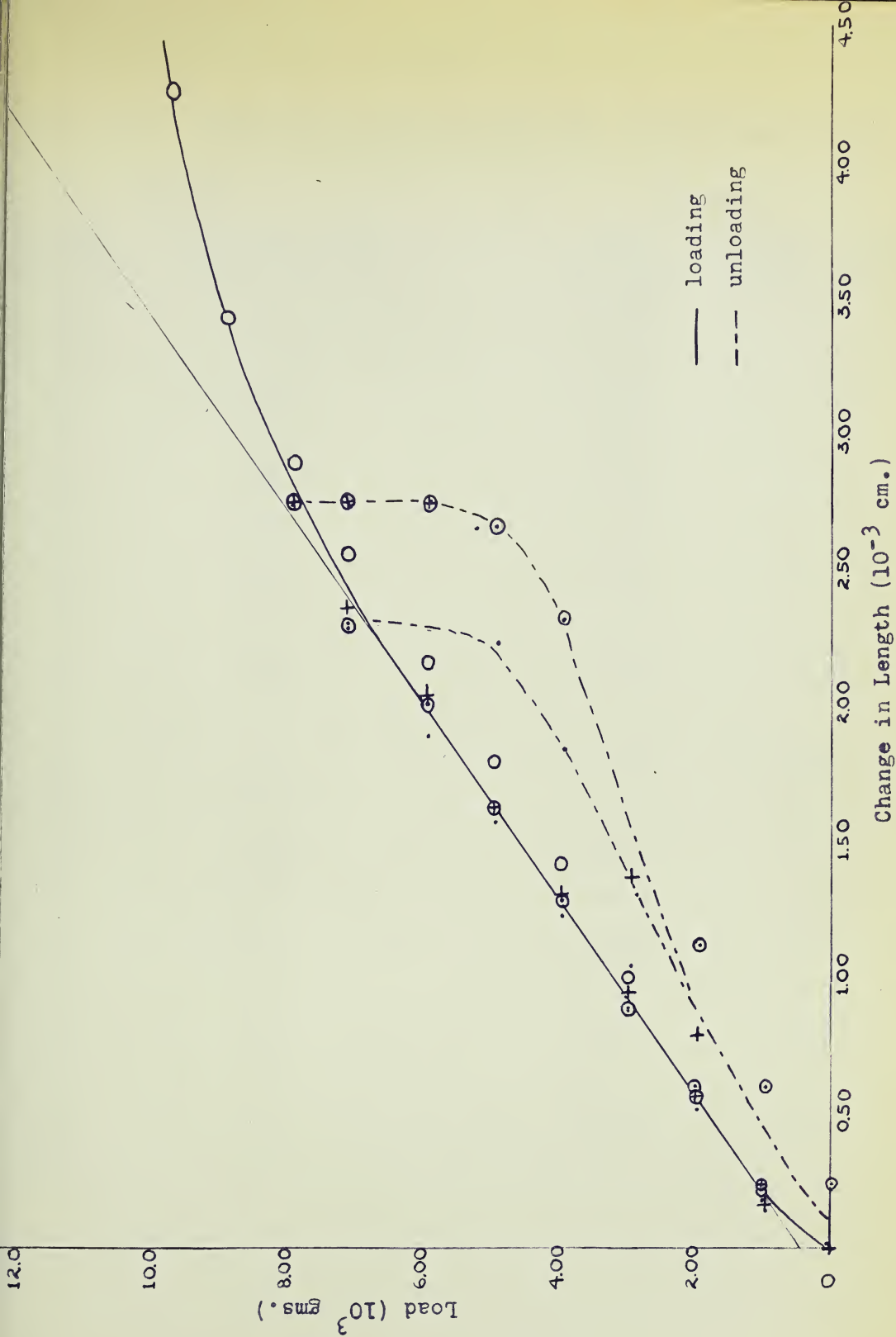


Fig. XXIII. Aluminum Crystal Annealed at  $200^{\circ}\text{C}$ .  
Liquid Nitrogen Temperature



TABLE XXIV. Magnesium Crystal as Received. Temperature 21.6°C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	7.80	5.62
0.990	0.385	6.80	5.62
1.97	0.983	5.81	5.42
2.94	1.71	4.83	4.73
3.91	2.48	3.86	4.05
4.89	3.24	2.88	3.50
5.86	4.00	1.90	2.93
6.83	4.75	0.930	2.18
7.80	5.62	-0.045	1.29
0	0	7.82	5.25
1.00	0.128	7.32	5.25
1.98	0.618	6.82	5.25
2.95	1.33	5.84	4.61
3.93	1.97	4.86	4.11
4.90	2.67	3.88	3.52
5.88	3.42	2.90	2.88
6.85	4.36	1.92	2.18
7.33	4.65	0.935	1.45
7.82	5.25	0	0



TABLE XXIV. cont'd. Magnesium Crystal as Received.  
Temperature 21.6°C.

<u>Loading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0
0.985	0.426
1.96	1.09
2.94	1.80
3.92	2.40
4.89	3.12
5.86	3.85
6.84	4.56
7.33	4.95
7.81	5.33
8.30	5.75
8.78	6.23
9.26	6.86



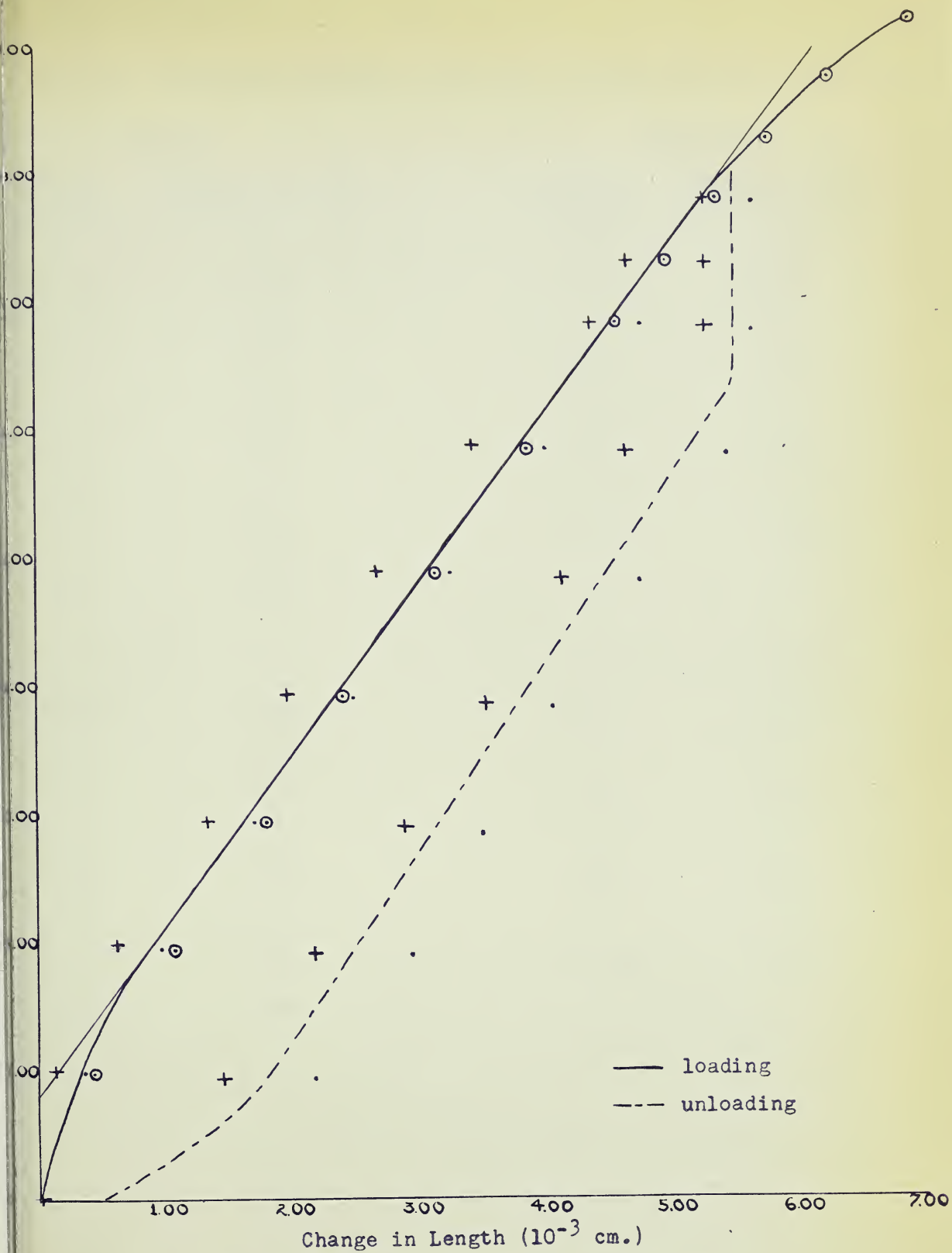


Fig. XXIV. Magnesium Crystal as Received.  
Temperature  $21.6^{\circ}$  C.



TABLE XXV. Magnesium Crystal as Received. Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	7.85	4.40
0.992	0.214	6.85	4.27
1.97	0.810	5.87	3.61
2.95	1.41	4.89	3.14
3.93	1.97	3.91	2.54
4.91	2.56	2.93	1.98
5.89	3.21	1.95	1.26
6.87	3.80	0.980	0.597
7.85	4.40	0	0
0	0	7.84	4.46
0.995	0.150	6.85	4.37
1.98	0.682	5.87	3.74
2.95	1.30	4.89	3.05
3.93	1.94	3.91	2.59
4.91	2.63	2.97	1.95
5.89	3.21	1.95	1.30
6.87	3.82	0.978	0.620
7.84	4.46	0	0



TABLE XXV. cont'd. Magnesium Crystal as Received.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	9.80	5.80
0.995	0.128	9.30	5.80
1.97	0.682	8.80	5.70
2.95	1.28	7.82	5.08
3.93	1.92	6.84	4.60
4.91	2.56	5.86	4.05
5.89	3.23	4.88	3.40
6.87	3.82	3.91	2.67
7.84	4.49	2.93	2.05
8.82	5.10	1.95	1.43
9.31	5.46	0.970	0.790
9.80	5.80	0	0
0	0		
0.992	0.213		
1.97	0.832		
2.95	1.50		
3.93	2.11		
4.90	2.82		
5.88	3.45		
6.85	4.15		
7.83	4.75		
8.81	5.40		
9.79	6.09		
10.8	6.78		
11.7	7.50		
12.3	7.90		
12.7	8.32		



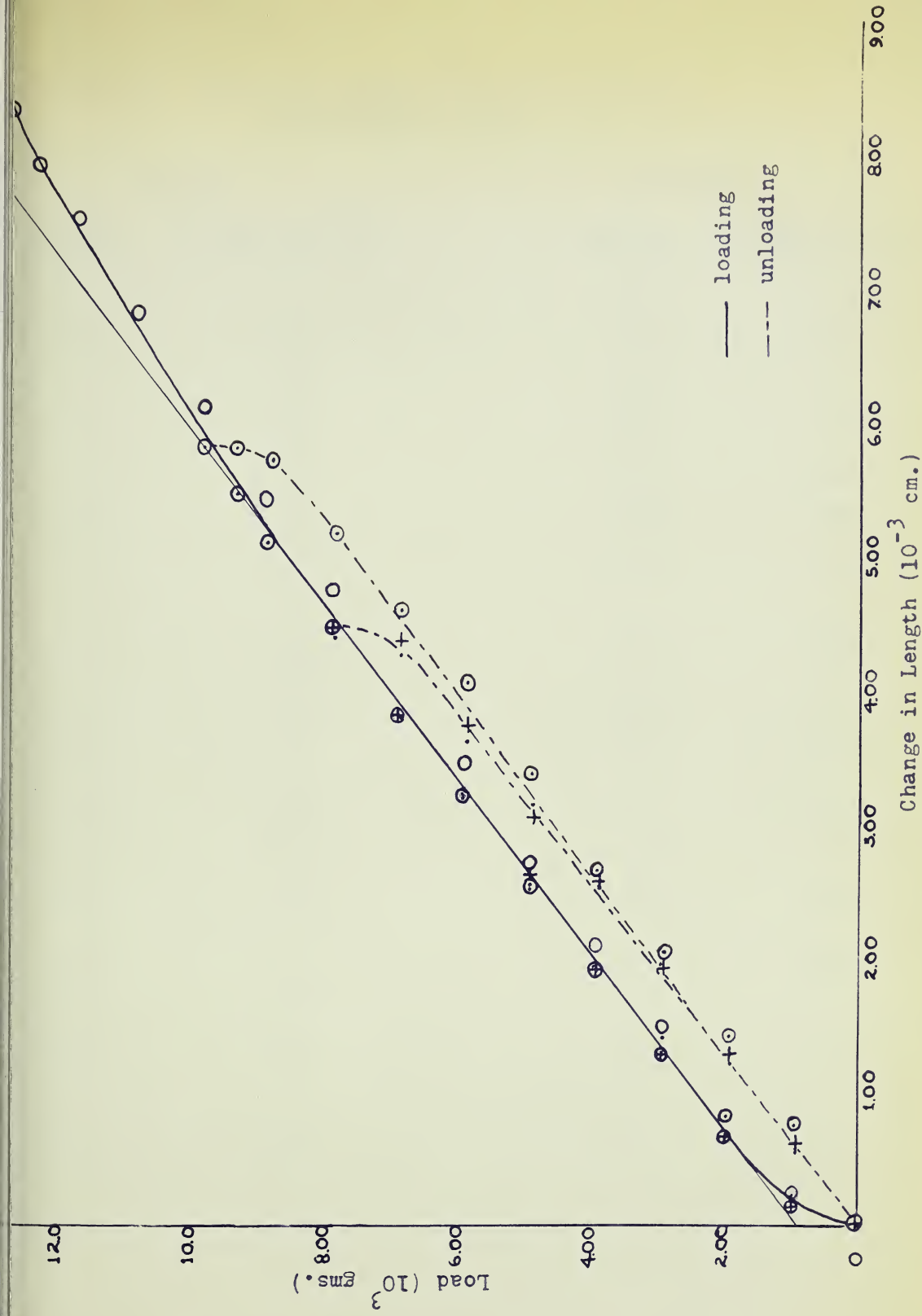


Fig. XXV. Magnesium Crystal as Received.  
Liquid Nitrogen Temperature.



TABLE XXVI. Magnesium Crystal Annealed at 200°C.  
Temperature 25.0°C.

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	4.89	3.14
1.00	0.171	4.39	3.14
1.97	0.940	3.89	3.14
2.94	1.64	2.90	2.75
3.92	2.37	1.93	1.98
4.40	2.71	0.955	1.26
4.89	3.14	-0.010	0.363
0	0	4.89	3.14
1.00	0.085	4.39	3.14
1.97	0.768	3.89	3.14
2.94	1.64	2.91	2.65
3.92	2.39	1.93	2.01
4.40	2.73	0.955	1.30
4.89	3.14	-0.010	0.384
0	0	4.89	3.20
1.00	0.085	4.39	3.20
1.97	0.852	3.89	3.20
2.94	1.71	2.91	2.58
3.91	2.48	1.94	1.75
4.40	2.85	0.960	1.13
4.89	3.20	0	0



TABLE XXVI. cont'd. Magnesium Crystal Annealed at 200°C.  
Temperature 25.0°C.

<u>Loading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0
1.00	0.107
1.97	0.873
2.94	1.73
3.91	2.56
4.88	3.33
5.37	3.66
5.85	4.18
6.33	4.70
6.82	5.22



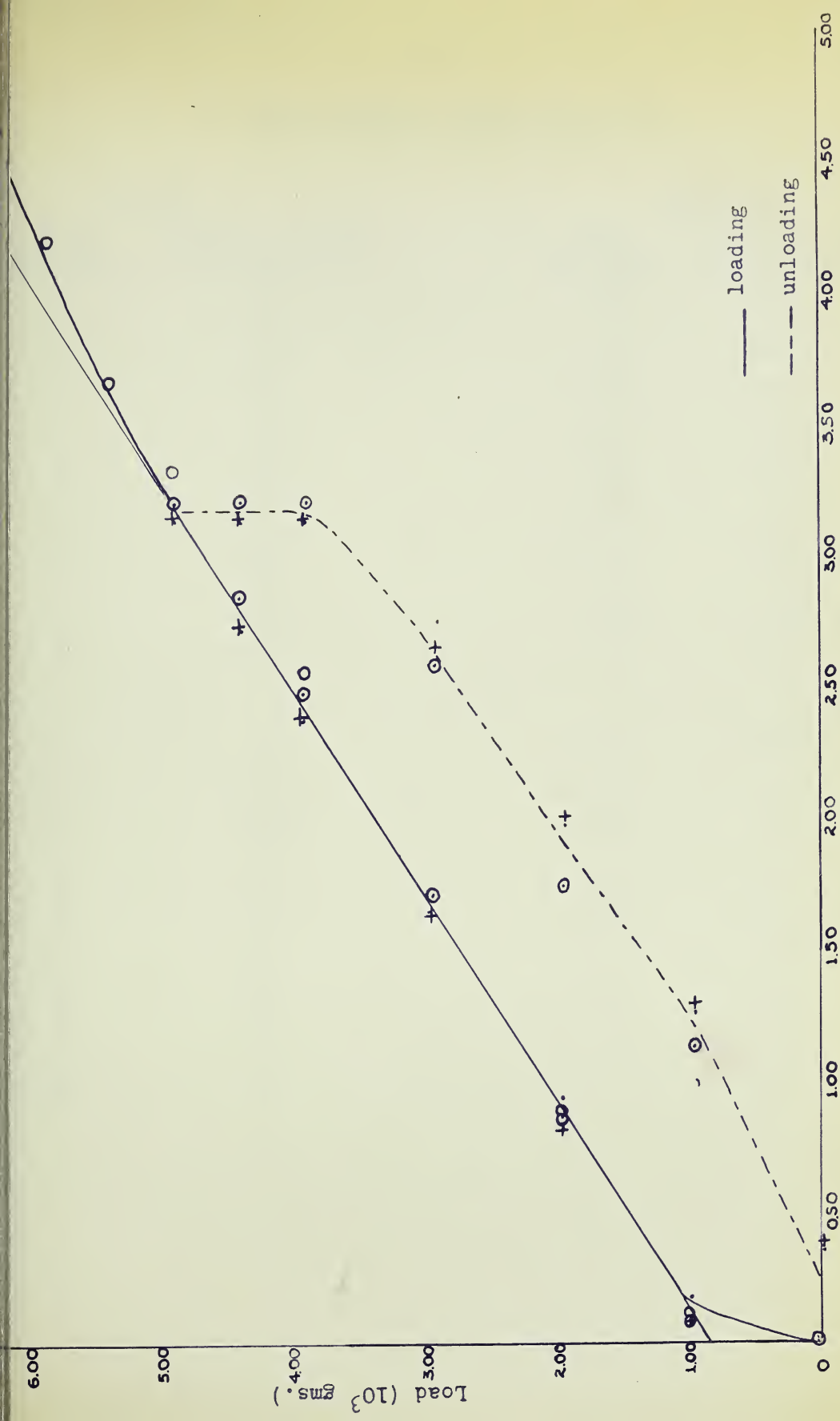


Fig. XXVI. Magnesium Crystal Annealed at  $200^{\circ}$  C.  
 Temperature  $25.0^{\circ}$  C.



TABLE XXVII. Magnesium Crystal Annealed at 200°C.  
Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	5.87	3.70
0.980	0.553	5.37	3.70
1.96	1.13	4.87	3.70
2.94	1.75	4.37	3.70
3.92	2.39	3.87	3.63
4.40	2.75	2.91	2.69
4.89	3.03	1.94	1.66
5.38	3.36	0.970	0.790
5.87	3.70	0	0
0	0	5.88	3.45
0.990	0.384	5.38	3.45
1.97	0.940	4.88	3.45
2.94	1.62	4.38	3.45
3.92	2.29	3.88	3.37
4.41	2.56	2.91	2.53
4.90	2.87	1.95	1.48
5.39	3.20	0.985	0.490
5.88	3.45	0	0

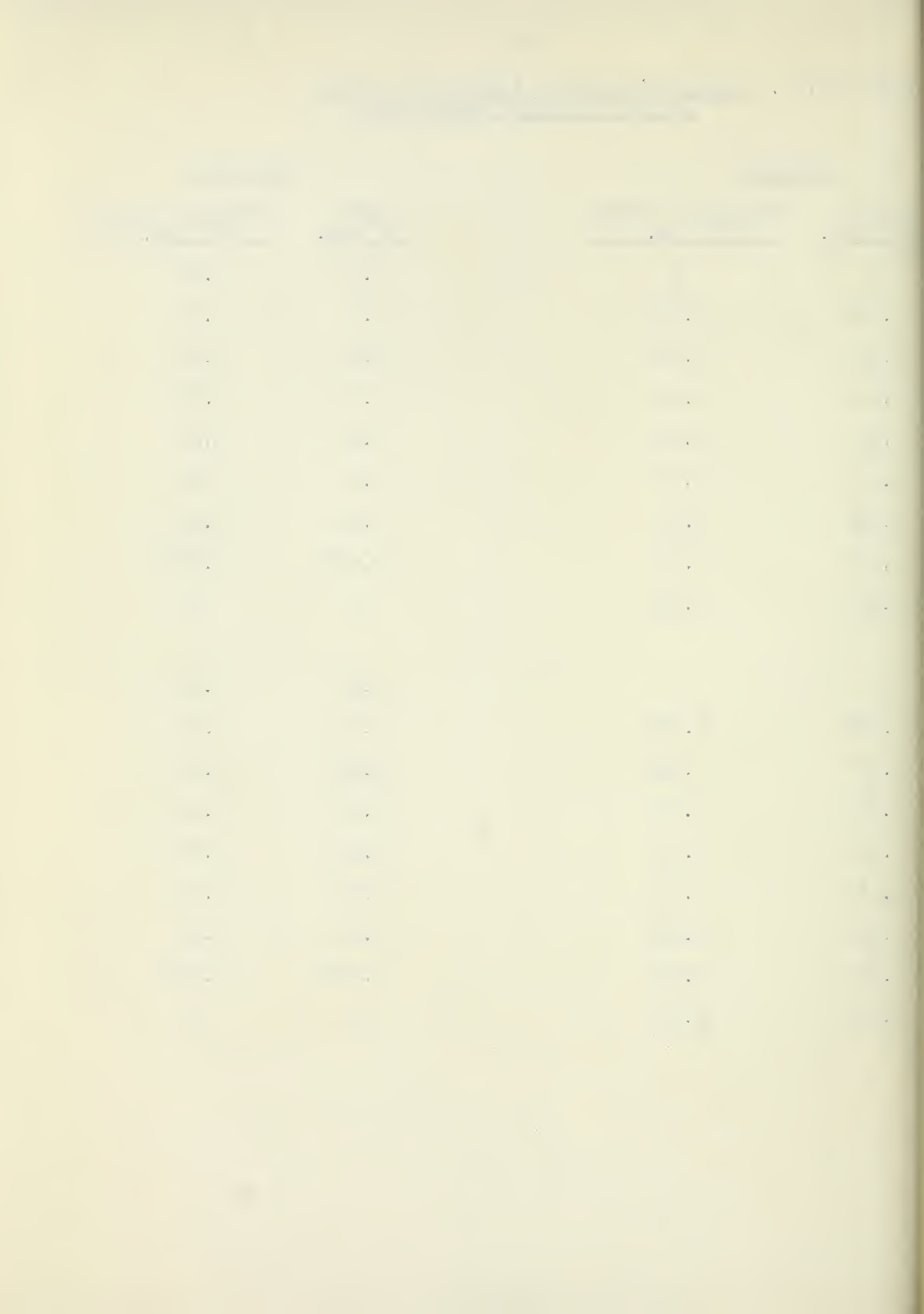
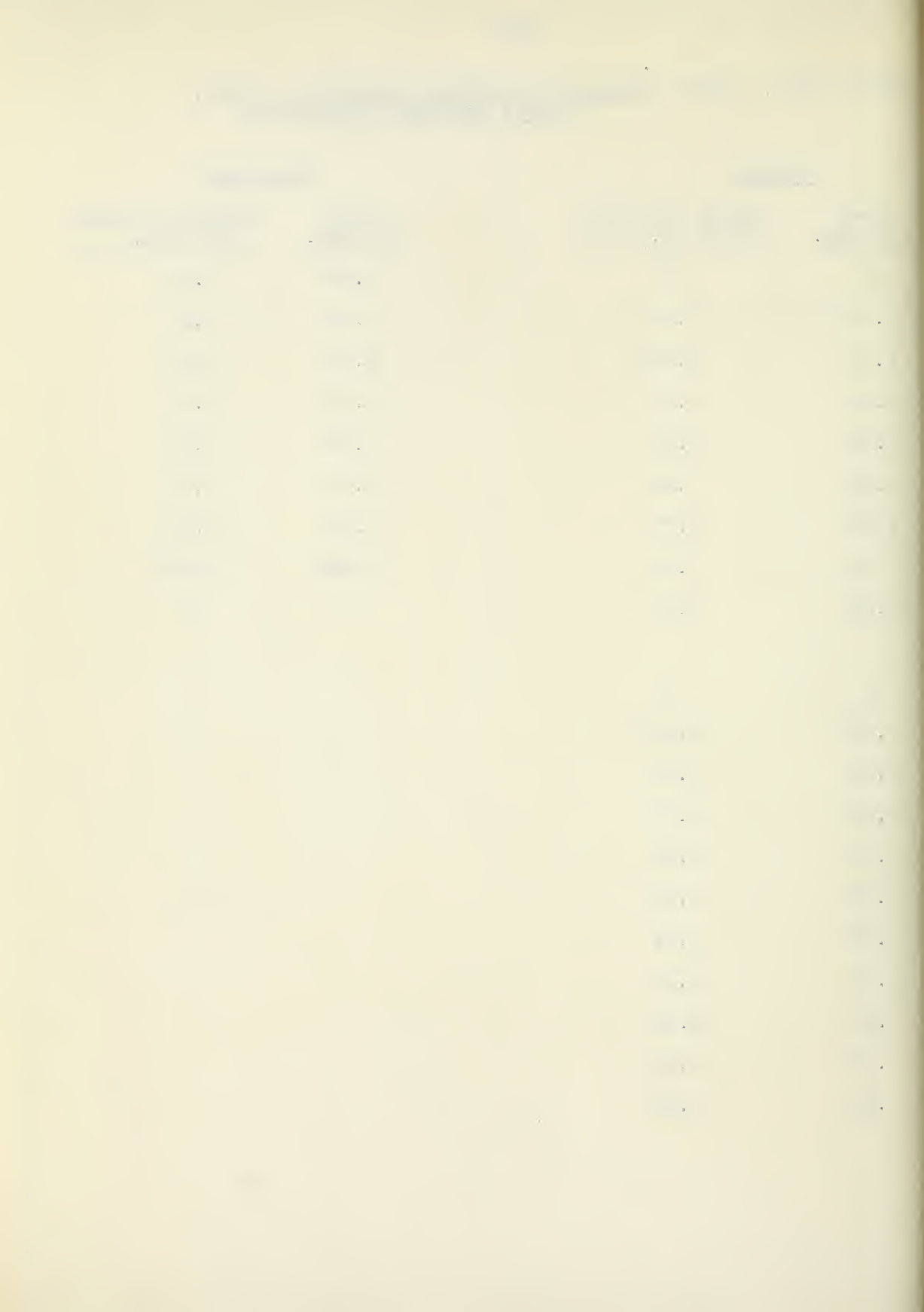


TABLE XXVII. cont'd. Magnesium Crystal Annealed at 200°C.  
Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>	
<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>	<u>Load</u> <u>10<sup>3</sup> gms.</u>	<u>Change in Length</u> <u>10<sup>-3</sup> cm.</u>
0	0	5.88	3.41
0.990	0.341	5.38	3.41
1.97	0.875	4.88	3.41
2.94	1.56	4.38	3.41
3.92	2.22	3.88	3.32
4.41	2.48	2.91	2.70
4.90	2.77	1.95	1.50
5.39	3.10	0.985	0.470
5.88	3.41	0	0
0	0		
0.985	0.426		
1.95	1.04		
2.94	1.75		
3.91	2.46		
4.89	3.07		
5.87	3.78		
6.36	4.10		
6.85	4.40		
7.33	4.82		
7.82	5.23		



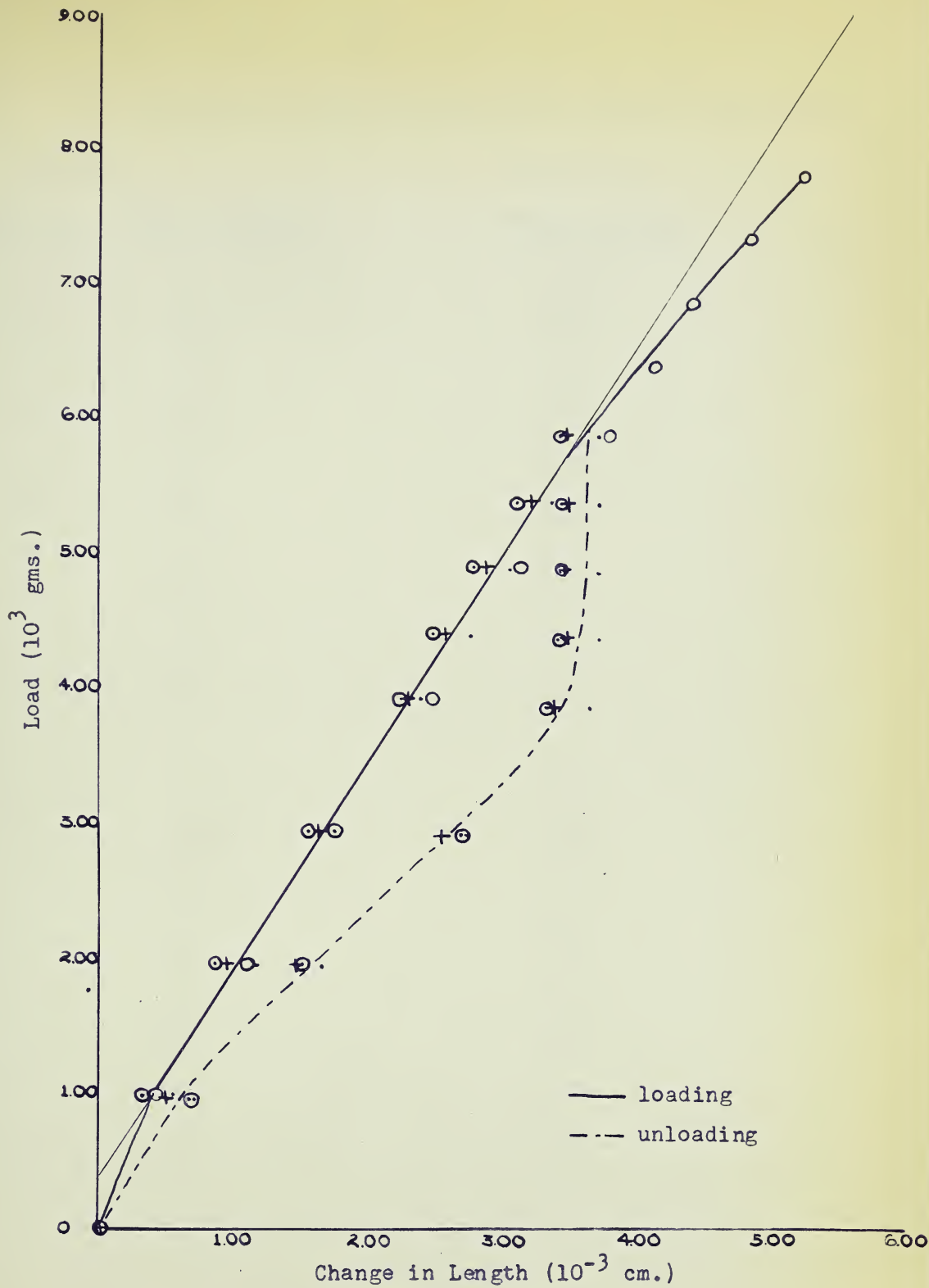


Fig. XXVII. Magnesium Crystal Annealed at  $200^{\circ}$  C.  
Liquid Nitrogen Temperature



TABLE XXVIII. Brass Crystal Annealed at 500°C. Temperature 25.4°C.

<u>Loading</u>		<u>Unloading</u>
<u><math>10^3</math> Torque gm. cm.</u>	<u>Angle of Twist <math>10^{-2}</math> radians</u>	<u>Angle of Twist <math>10^{-2}</math> radians</u>
0	0	0.130
1.30	0.570	0.700
2.60	1.12	1.28
3.90	1.70	1.86
5.20	2.21	2.41
6.50	2.75	2.98
7.80	3.32	3.51
8.32	3.52	3.71
8.84	3.76	3.87
9.36	4.00	4.00
0	0	0.010
1.30	0.555	0.640
2.60	1.12	1.23
3.90	1.69	1.81
5.20	2.20	2.35
6.50	2.73	2.90
7.80	3.29	3.45
8.32	3.52	3.65
8.84	3.76	3.81
9.36	3.94	3.94



TABLE XXVIII. cont'd. Brass Crystal Annealed at 500°C.  
Temperature 25.4°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>3</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.750
1.30	0.555	1.38
2.60	1.10	1.95
3.90	1.63	2.55
5.20	2.20	3.09
6.50	2.76	3.68
7.80	3.35	4.21
9.10	3.91	4.72
10.4	5.09	5.09

CONTENTS	ORIGINAL ARTICLES	DEPARTMENTS
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health
The Medical Profession and the Public Health	The Medical Profession and the Public Health	The Medical Profession and the Public Health

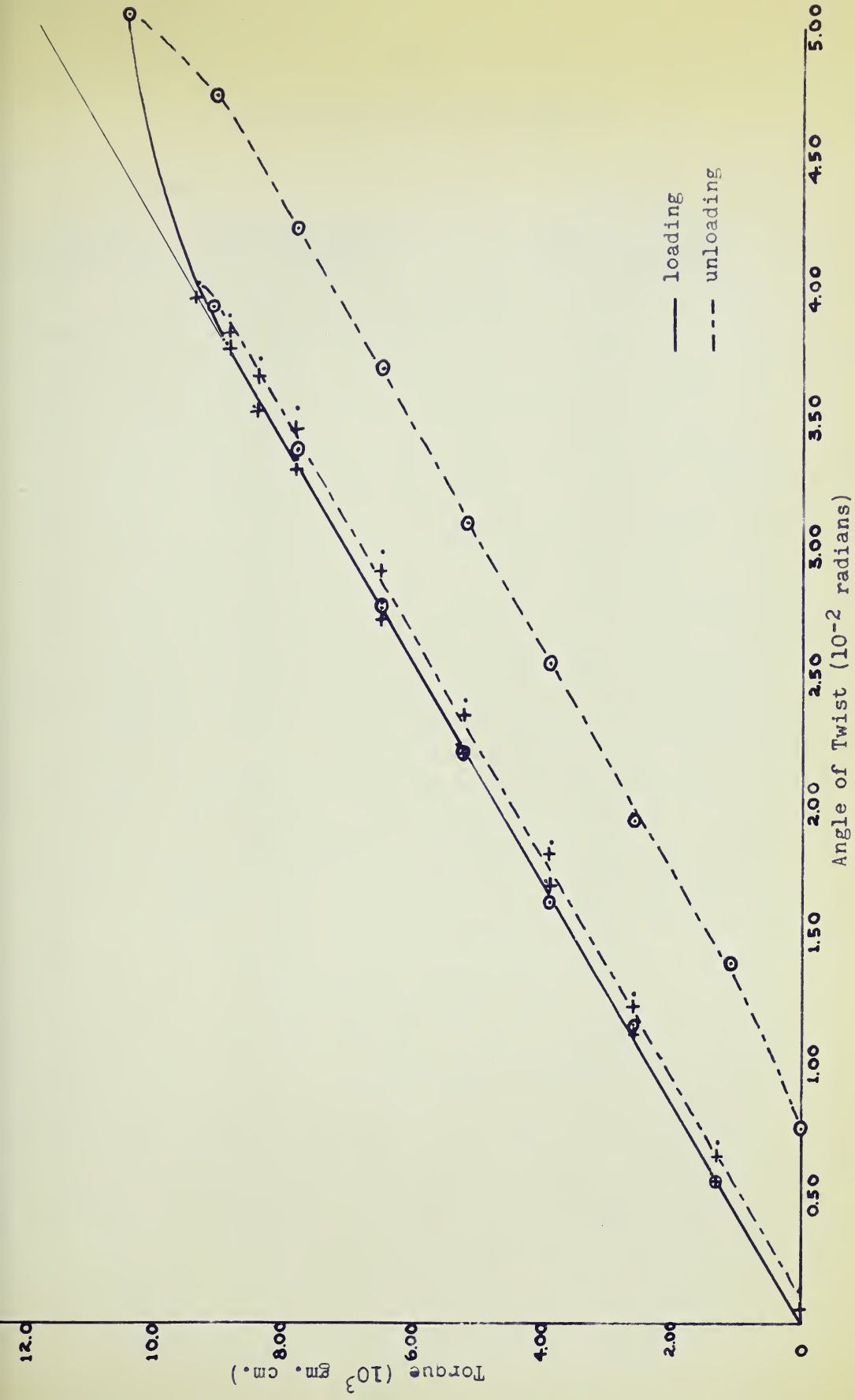


Fig. XXVIII. Brass Crystal Annealed at 500° C.  
Temperature 25.4° C.



TABLE XXIX. Brass Crystal Annealed at 500°C.  
Liquid Nitrogen Temperature.

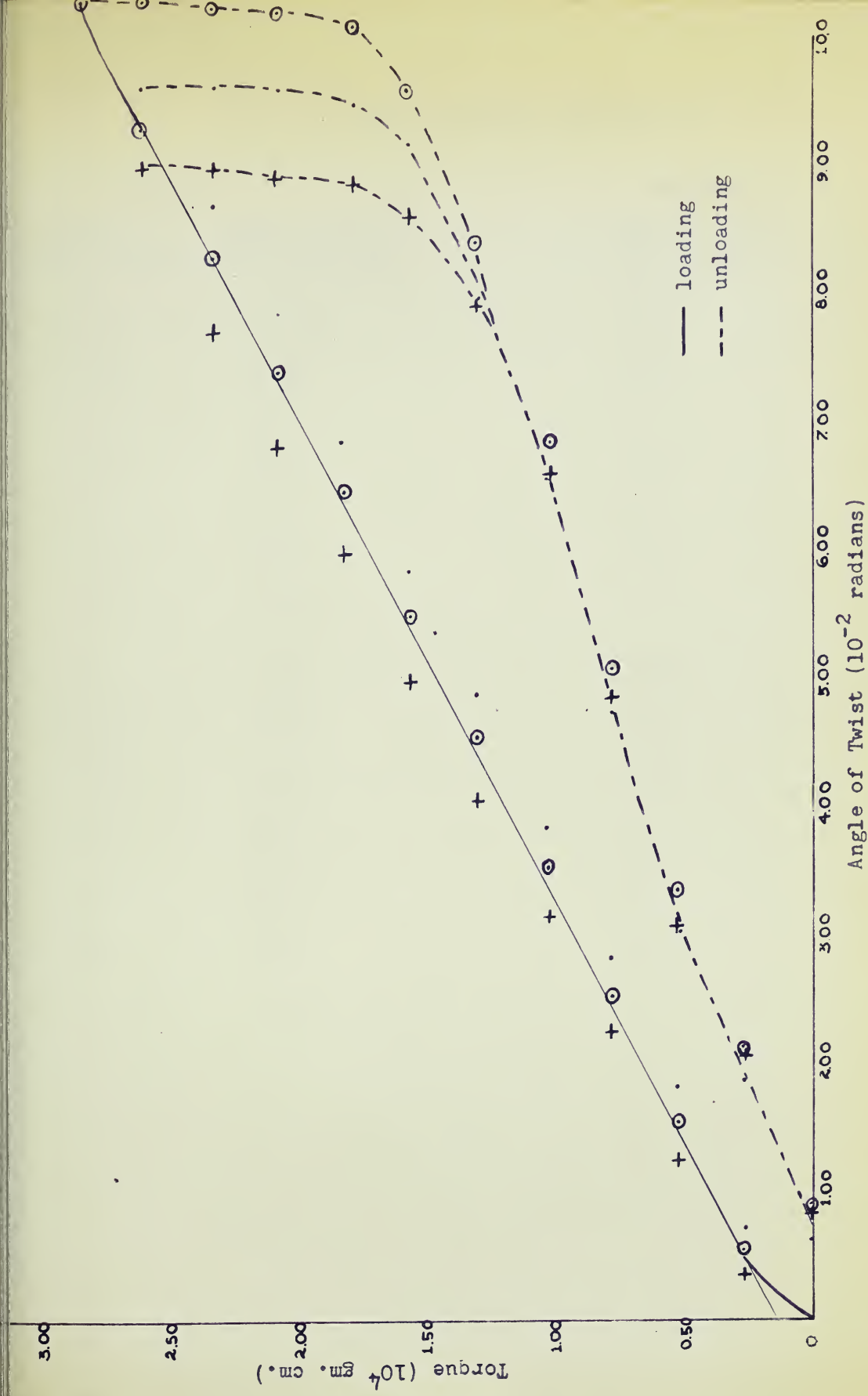
<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>4</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.615
0.260	0.710	1.88
0.520	1.81	3.02
0.780	2.81	4.73
1.04	3.85	6.55
1.30	4.89	7.95
1.56	5.83	9.11
1.82	6.84	9.44
2.08	7.81	9.56
2.34	8.66	9.58
2.60	9.58	9.58
0	0	0.820
0.260	0.335	2.08
0.520	1.26	3.05
0.780	2.22	4.85
1.04	3.14	6.58
1.30	4.04	7.89
1.56	4.98	8.59
1.82	5.98	8.83
2.08	6.79	8.88
2.34	7.68	8.94
2.60	8.94	8.94



TABLE XXIX. cont'd. Brass Crystal Annealed at 500°C.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>4</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.885
0.260	0.555	2.10
0.520	1.56	3.44
0.780	2.53	5.09
1.04	3.52	6.83
1.30	4.53	8.39
1.56	5.49	9.55
1.82	6.44	10.14
2.08	7.38	10.35
2.34	8.25	10.39
2.60	9.24	10.42
2.86	10.42	10.42





Angle of Twist ( $10^{-2}$  radians)

Fig. XXIX. Brass Crystal Annealed at  $500^{\circ} \text{ C.}$   
Liquid Nitrogen Temperature



TABLE XXX. Brass Crystal, Heated at 500°C. and Quenched.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>4</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.660
0.260	0.975	1.77
0.520	2.12	2.86
0.780	3.22	4.18
1.04	4.40	5.33
1.30	5.40	6.47
1.56	6.52	7.47
1.82	7.83	7.83
0	0	0.030
0.260	0.975	1.08
0.520	1.87	2.36
0.780	3.23	3.53
1.04	4.17	4.75
1.30	5.25	5.92
1.56	6.36	6.87
1.82	7.34	7.34

# CONTENTS

Original Articles  
Clinical Reports

Original Articles  
Clinical Reports

Original Articles  
Clinical Reports

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32
33	34	35	36
37	38	39	40
41	42	43	44
45	46	47	48
49	50	51	52
53	54	55	56
57	58	59	60
61	62	63	64
65	66	67	68
69	70	71	72
73	74	75	76
77	78	79	80
81	82	83	84
85	86	87	88
89	90	91	92
93	94	95	96
97	98	99	100

TABLE XXXcont'd. Brass Crystal, Heated at 500°C. and Quenched.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>4</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.220
0.260	1.09	1.28
0.520	2.02	2.55
0.780	3.17	3.75
1.04	4.25	4.94
1.30	5.41	6.07
1.56	6.40	7.09
1.82	7.49	7.49
0	0	0.14
0.260	0.950	1.40
0.520	1.90	2.50
0.780	3.20	3.75
1.04	4.19	4.99
1.30	5.30	6.13
1.56	6.39	7.77
1.82	7.39	8.27
2.08	8.61	8.61



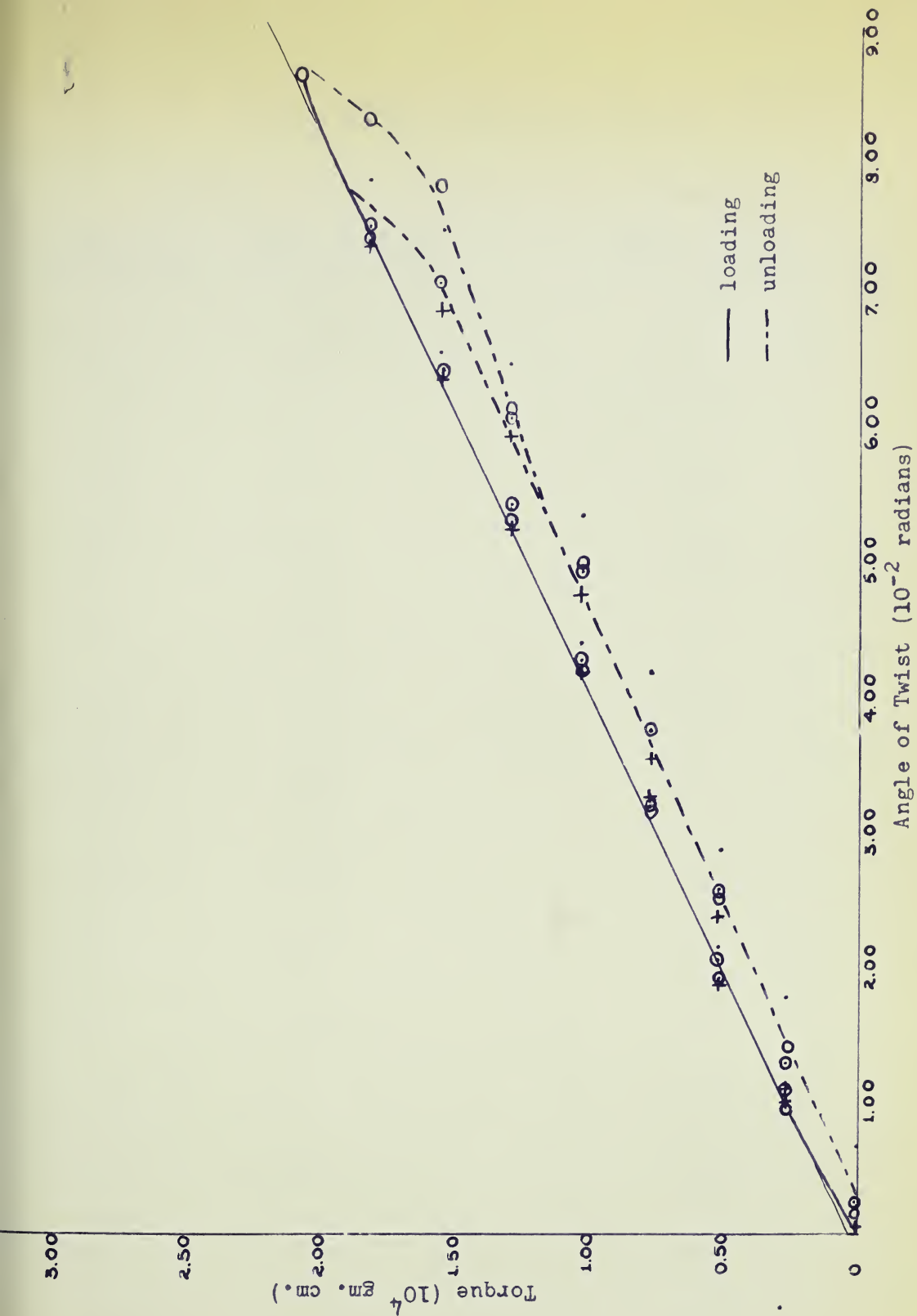


Fig. XXX. Brass Crystal, Heated at  $500^{\circ}$  C. and Quenched.  
Liquid Nitrogen Temperature



TABLE XXXI . Brass Crystal Annealed at 500°C. and Quenched from 450°C. Temperature 22.0°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>3</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.500
2.60	1.17	1.32
5.20	2.40	2.56
7.80	3.61	3.79
9.10	4.17	4.40
10.4	4.79	4.95
11.7	5.36	5.51
13.0	5.91	5.91
0	0	0.30
2.60	1.16	1.75
5.20	2.35	2.51
7.80	3.55	3.72
9.10	4.16	4.35
10.4	4.75	4.94
11.7	5.32	5.46
13.0	5.86	5.86
0	0	0.530
2.60	1.17	1.87
5.20	2.36	3.08
7.80	3.53	4.28
10.4	4.73	5.42
11.7	5.27	6.01
13.0	5.83	6.63
14.3	6.98	6.98



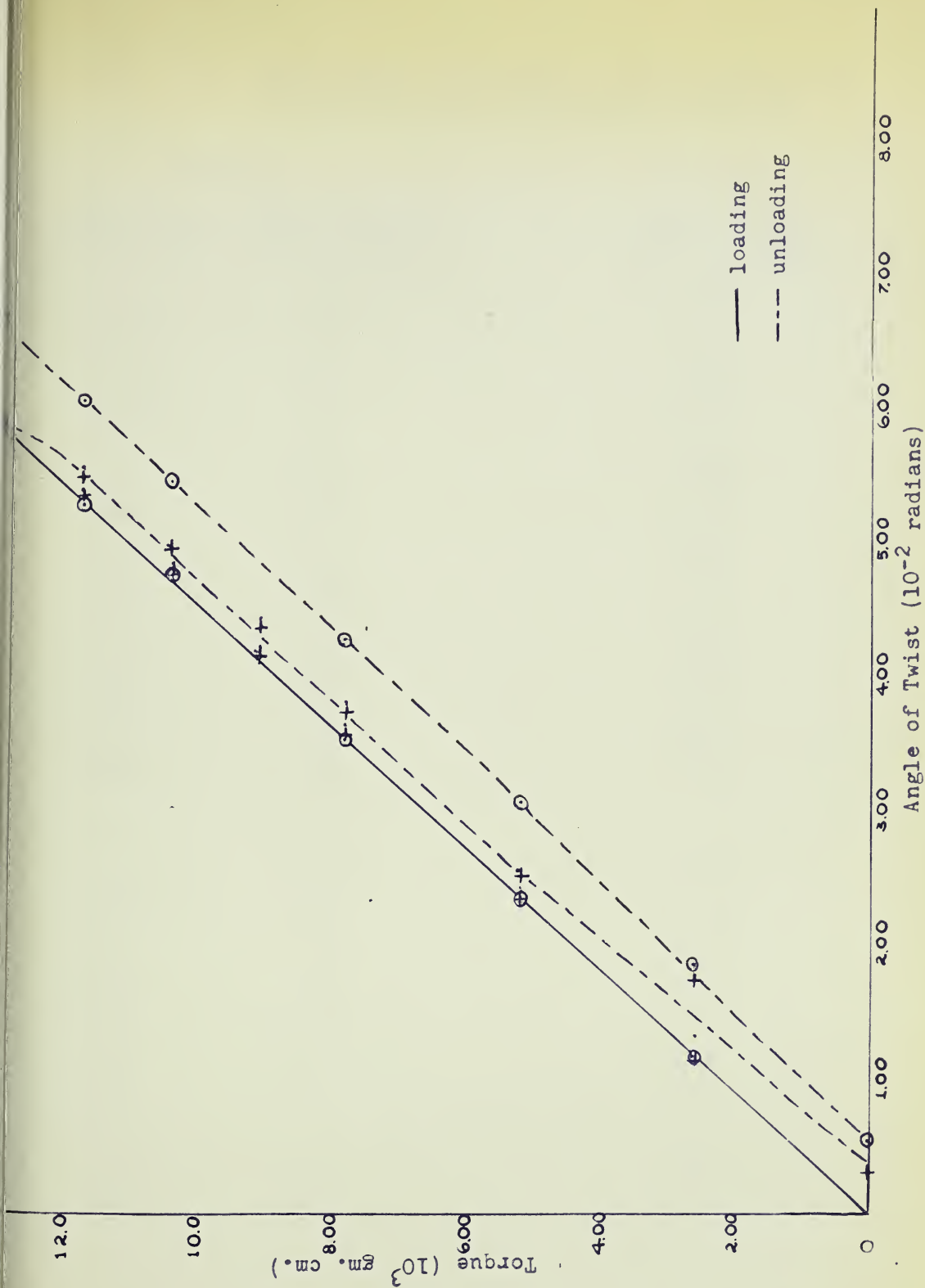


Fig. XXXI. Brass Crystal Annealed at  $500^{\circ}$  C. and Quenched from  $450^{\circ}$  C.  
Temperature  $22.0^{\circ}$  C.



TABLE XXXII. Brass Crystal Annealed at 500°C. and Quenched  
from 450°C. Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>4</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.020
0.260	1.11	1.23
0.520	2.36	2.45
0.780	3.46	3.64
1.04	4.50	4.86
1.30	5.80	6.02
1.43	6.37	6.55
1.56	6.98	7.20
1.69	7.52	7.80
1.82	8.02	8.33
1.95	8.66	8.84
2.08	9.20	9.20
0	0	0.02
0.260	1.14	1.23
0.520	2.25	2.43
0.780	3.44	3.60
1.04	4.59	4.83
1.30	5.75	5.95
1.56	6.93	7.11
1.82	8.00	8.25
2.08	9.18	9.18



TABLE XXXII. cont'd. Brass Crystal Annealed at 500°C. and  
Quenched from 450°C.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>4</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.110
0.260	1.12	1.37
0.520	2.28	2.52
0.780	3.43	3.73
1.04	4.56	4.96
1.30	5.78	6.12
1.56	6.88	7.26
1.82	8.01	8.37
2.08	9.17	9.45
2.21	9.77	9.77



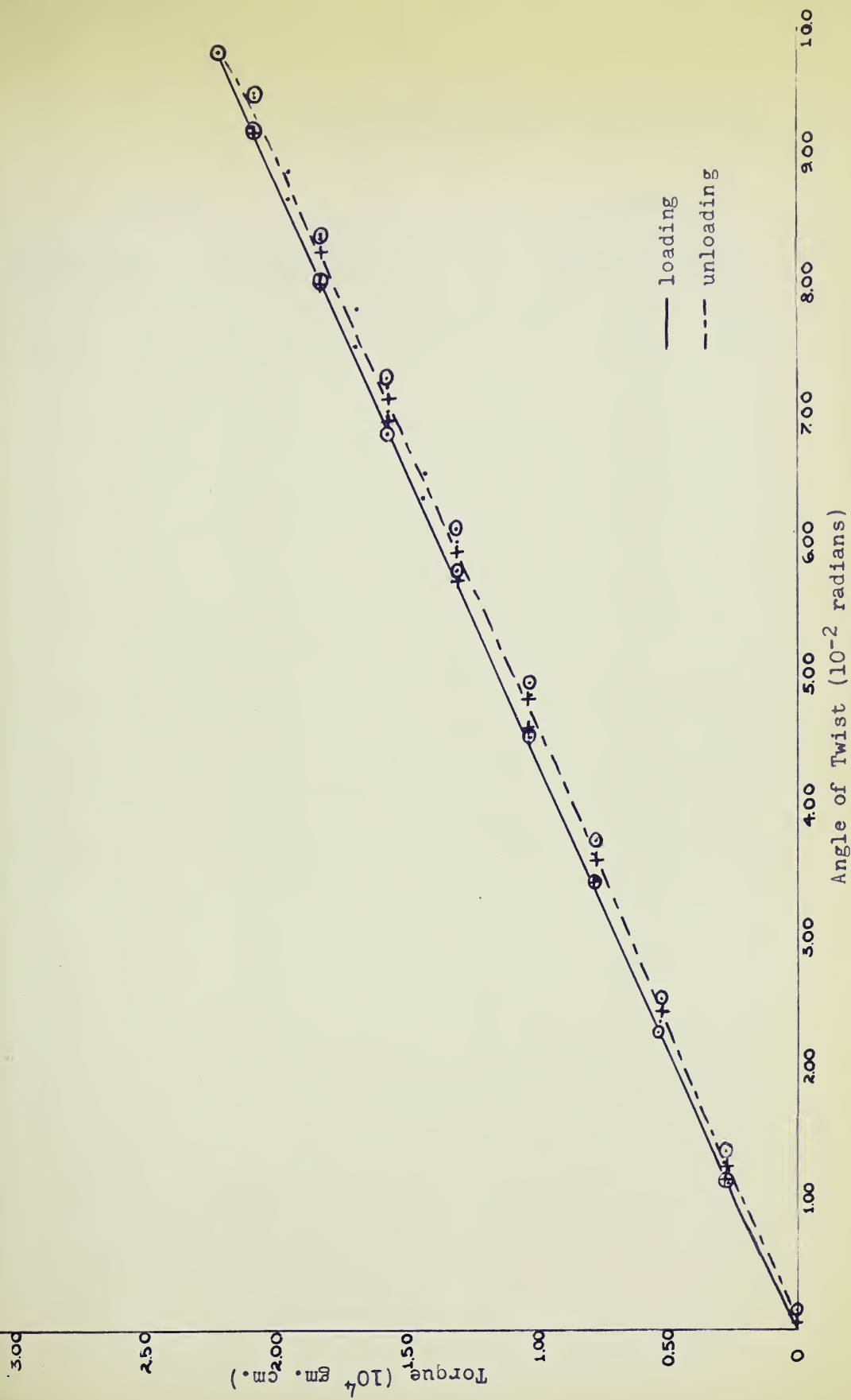


Fig. XXXII. Brass Crystal Annealed at  $500^{\circ} \text{ C.}$  and Quenched from  $450^{\circ} \text{ C.}$   
Liquid Nitrogen Temperature



TABLE XXXIII.

Brass Crystal Annealed at 500°C. and  
Quenched from 400°C. Temperature 22.8°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>3</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.320
2.60	1.17	1.62
5.20	2.33	2.88
7.80	3.53	4.03
9.10	4.11	4.63
10.4	4.84	5.21
11.7	5.37	5.72
13.0	6.01	6.01
0	0	0.050
2.60	1.16	1.35
5.20	2.35	2.60
7.80	3.52	3.75
9.10	4.06	4.33
10.4	4.61	4.91
11.7	5.21	5.43
13.0	5.73	5.73



TABLE XXXIII. cont'd. Brass Crystal Annealed at 500°C. and  
Quenched from 400°C. Temperature 22.8°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>3</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.030
2.60	1.15	1.32
5.20	2.35	2.54
7.80	3.49	3.70
9.10	4.04	4.27
10.4	4.65	4.87
11.7	5.19	5.40
13.0	5.71	5.71
0	0	0.110
2.60	1.17	1.42
5.20	2.32	2.65
7.80	3.47	3.82
9.10	4.03	4.46
10.4	4.62	4.99
11.7	5.18	5.62
13.0	5.67	6.12
14.3	6.22	6.61
15.6	6.92	6.92





Fig. XXXIII. Brass Crystal Annealed at  $500^{\circ}$  C. and Quenched from  $400^{\circ}$  C.  
 Temperature  $22.8^{\circ}$  C.



TABLE XXXIV. Brass Crystal Annealed at 500°C. and Quenched from 400°C. Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>4</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.120
0.260	1.11	1.31
0.520	2.22	2.43
0.780	3.36	3.61
1.04	4.47	4.76
1.17	5.10	5.35
1.30	5.66	5.92
1.43	6.22	6.51
1.56	6.77	7.00
1.69	7.35	7.52
1.82	7.87	7.87
0	0	0
0.260	1.10	1.15
0.520	2.20	2.30
0.780	3.28	3.49
1.04	4.39	4.60
1.17	4.99	5.21
1.30	5.55	5.80
1.43	6.10	6.34
1.56	6.64	6.85
1.69	7.22	7.36
1.82	7.70	7.70



TABLE XXXIV. cont'd. Brass Crystal Annealed at 500°C. and Quenched from 400°C. Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>4</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0
0.260	1.10	1.17
0.520	2.20	2.37
0.780	3.34	3.55
1.04	4.42	4.71
1.30	5.56	5.80
1.56	6.64	6.90
1.82	7.65	8.02
1.95	8.21	8.55
2.08	8.88	8.88
0	0	
0.260	1.09	
0.520	2.21	
0.780	3.33	
1.04	4.44	
1.30	5.59	
1.56	6.65	
1.82	7.64	
1.95	8.24	
2.08	8.80	
2.21	9.36	
2.34	9.92	
2.47	10.5	
2.60	11.1	
2.73	11.7	
2.86	12.8	



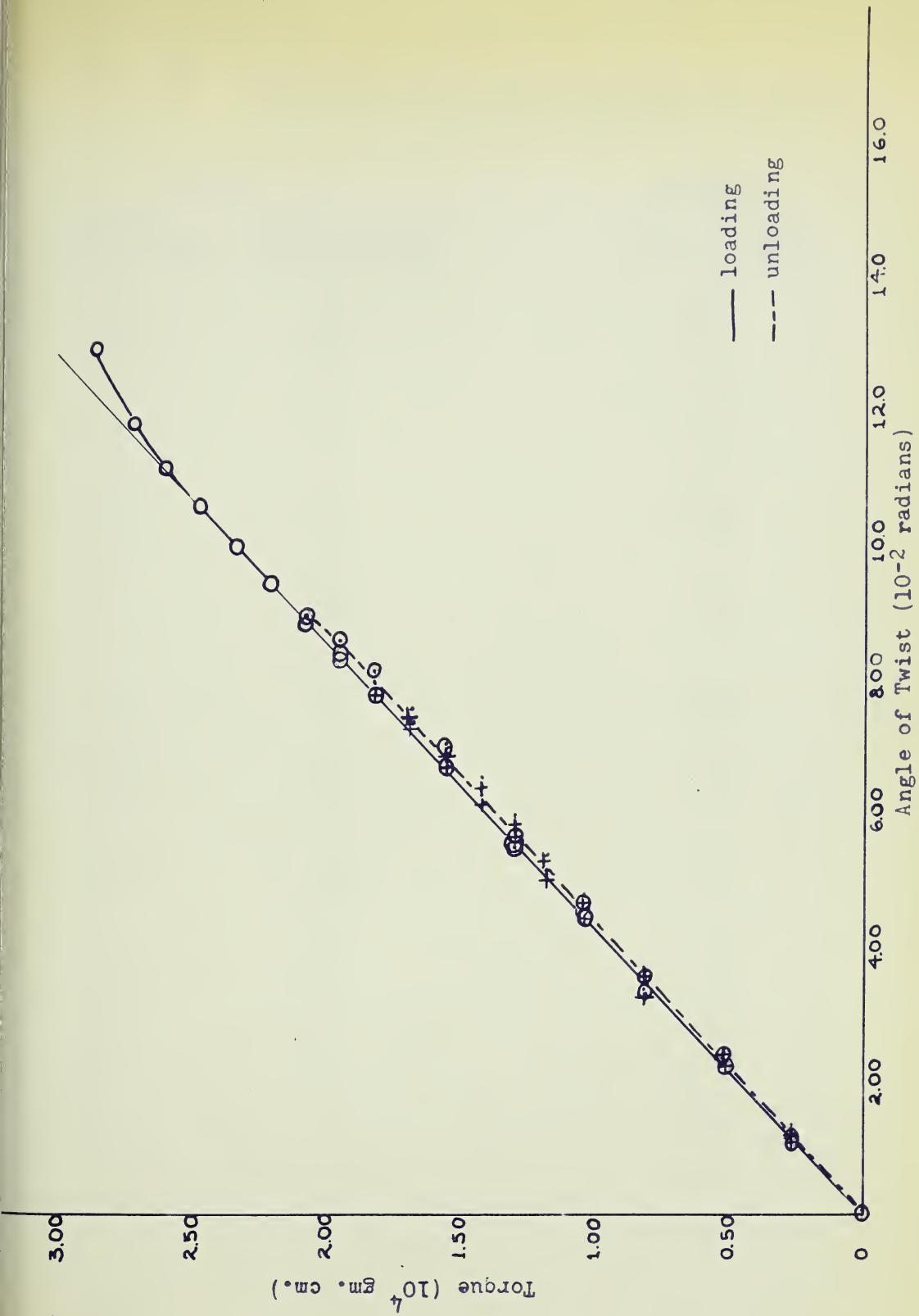


Fig. XXXIV. Brass Crystal Annealed at  $500^{\circ}$  C. and Quenched from  $400^{\circ}$  C.  
 Liquid Nitrogen Temperature



TABLE XXXV . Brass Crystal Heated at 575°C. and Quenched.  
Temperature 22.4°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>3</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.061
2.60	1.17	1.31
5.20	2.32	2.55
6.50	2.92	3.18
7.80	3.44	3.75
9.10	3.94	4.30
10.4	4.40	4.78
11.7	5.00	5.00
0	0	0.061
1.30	0.565	0.661
2.60	1.16	1.27
3.90	1.77	1.92
5.20	2.38	2.54
6.50	2.94	3.15
7.80	3.49	3.74
9.10	4.05	4.30
10.4	4.56	4.80
11.7	5.11	5.11



TABLE XXXV .cont'd. Brass Crystal Heated at 575°C. and Quenched. Temperature 22.4°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>3</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.101
2.60	1.17	1.35
5.20	2.35	2.58
6.50	2.98	3.22
7.80	3.53	3.79
9.10	4.05	4.33
10.4	4.55	4.85
11.7	5.12	5.12
0	0	0.530
1.30	0.555	1.12
2.60	1.15	1.77
3.90	1.75	2.41
5.20	2.36	2.98
6.50	2.93	3.61
7.80	3.53	4.22
9.10	4.03	4.78
10.4	4.55	5.33
11.7	5.03	5.78
13.0	5.93	5.93



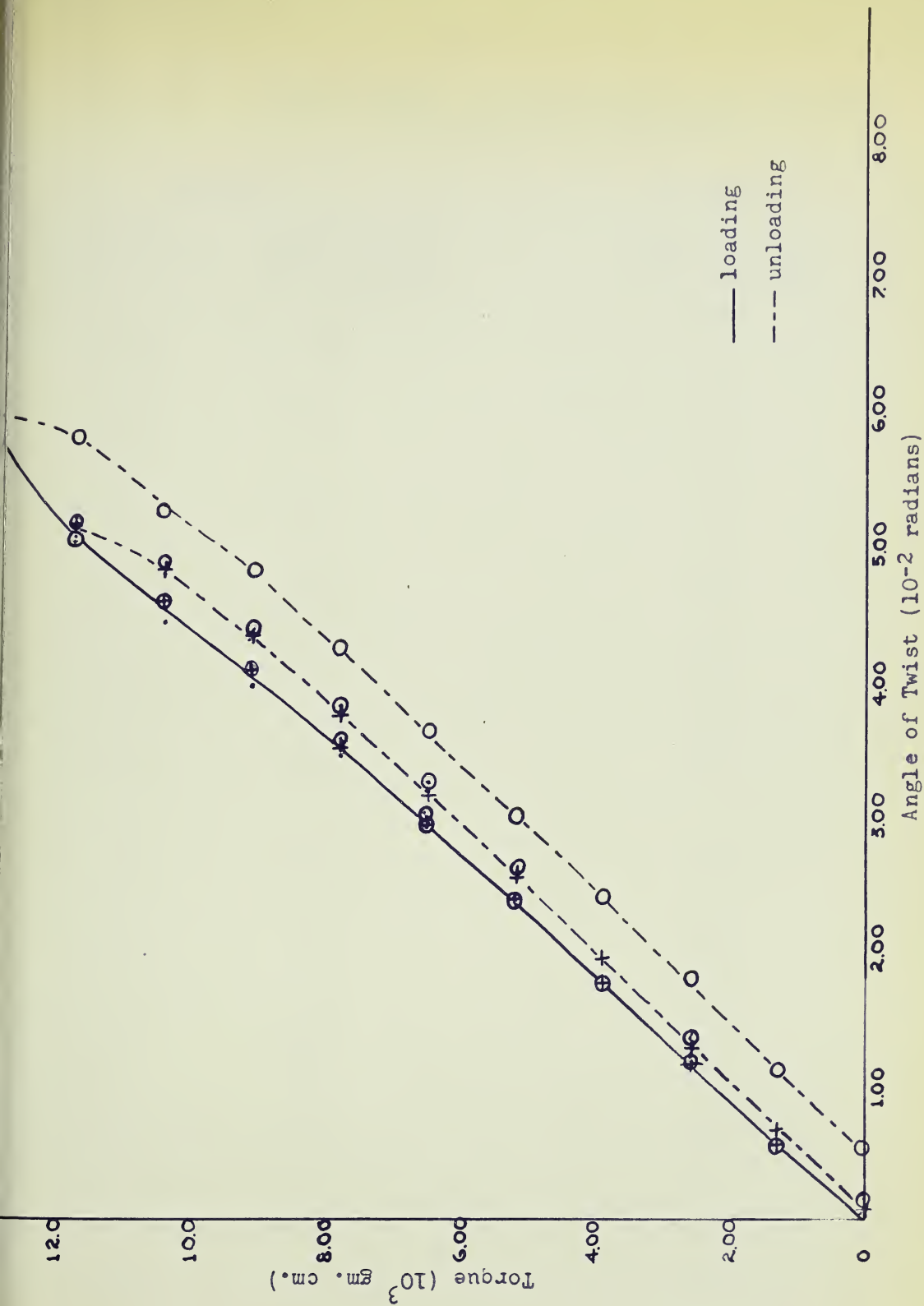


Fig. XXXV. Brass Crystal Heated at  $575^{\circ} \text{ C.}$  and Quenched.  
Temperature  $22.4^{\circ} \text{ C.}$



TABLE XXX VI. Brass Crystal Heated at 575°C. and Quenched.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>4</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.066
0.260	1.10	1.23
0.520	2.23	2.39
0.780	3.37	3.56
1.04	4.42	4.75
1.17	5.03	5.27
1.30	5.60	5.86
1.43	6.15	6.38
1.56	6.77	6.96
1.69	7.30	7.50
1.82	7.81	7.81
0	0	0.705
0.260	1.11	1.87
0.520	2.24	3.03
0.780	3.36	4.18
1.04	4.44	5.29
1.30	5.60	6.55
1.56	6.67	7.62
1.82	7.76	8.75
1.95	8.45	9.25
2.08	9.48	9.48



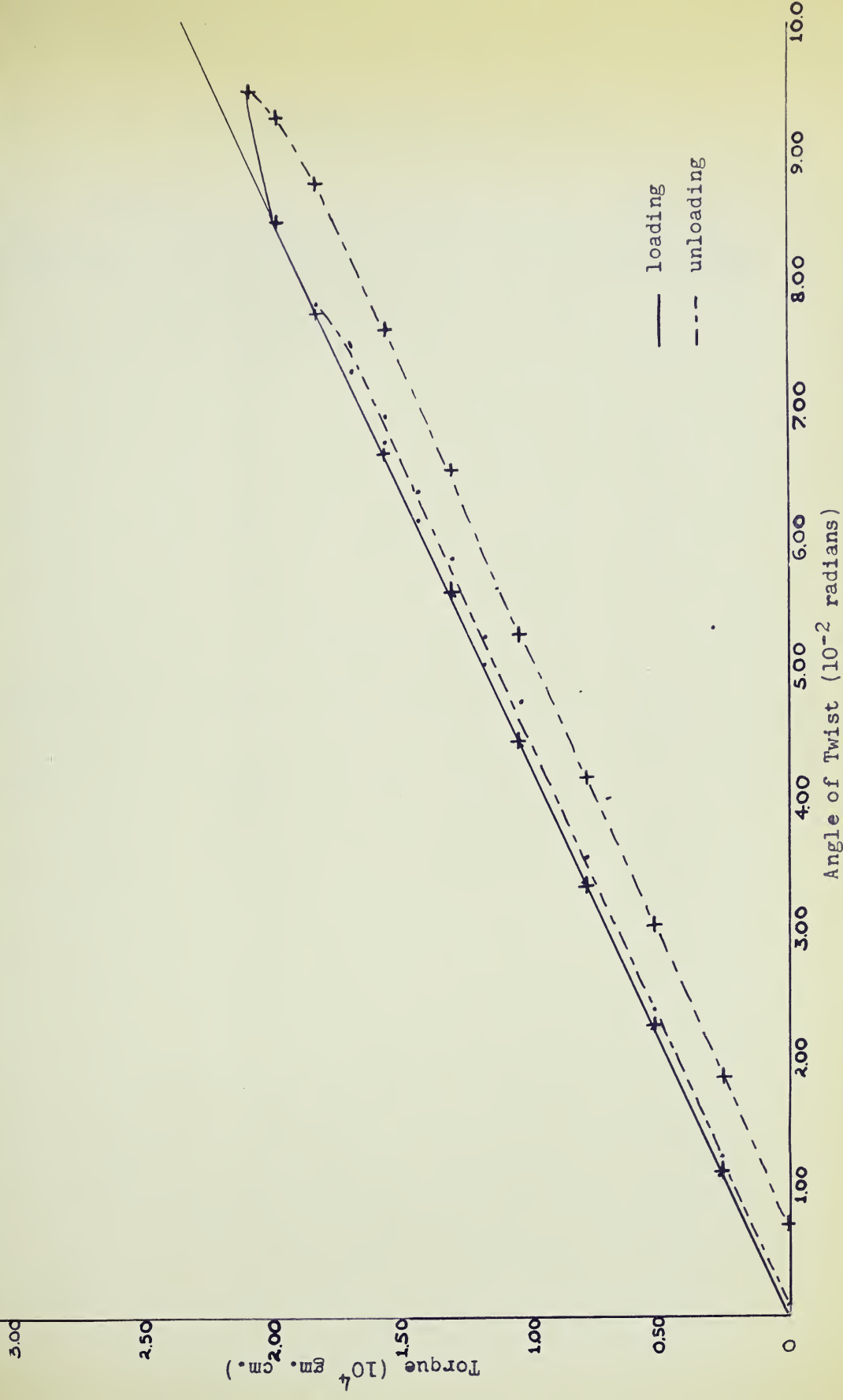


Fig. XXXVI. Brass Crystal Heated at  $575^{\circ} \text{ C.}$  and Quenched.  
Liquid Nitrogen Temperature.



TABLE XXXVII. Copper Crystal Annealed at 195°C.  
Temperature 23.8°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.840
6.50	2.75	3.65
7.80	3.31	--
9.10	3.86	4.56
10.4	4.39	4.94
11.7	4.81	5.30
13.0	5.41	5.41
0	0	0.44
6.50	2.43	3.35
7.80	2.91	3.79
9.10	3.34	--
10.4	3.79	4.75
11.7	4.32	5.24
13.0	4.79	5.69
14.3	5.28	5.88
15.6	5.88	5.88



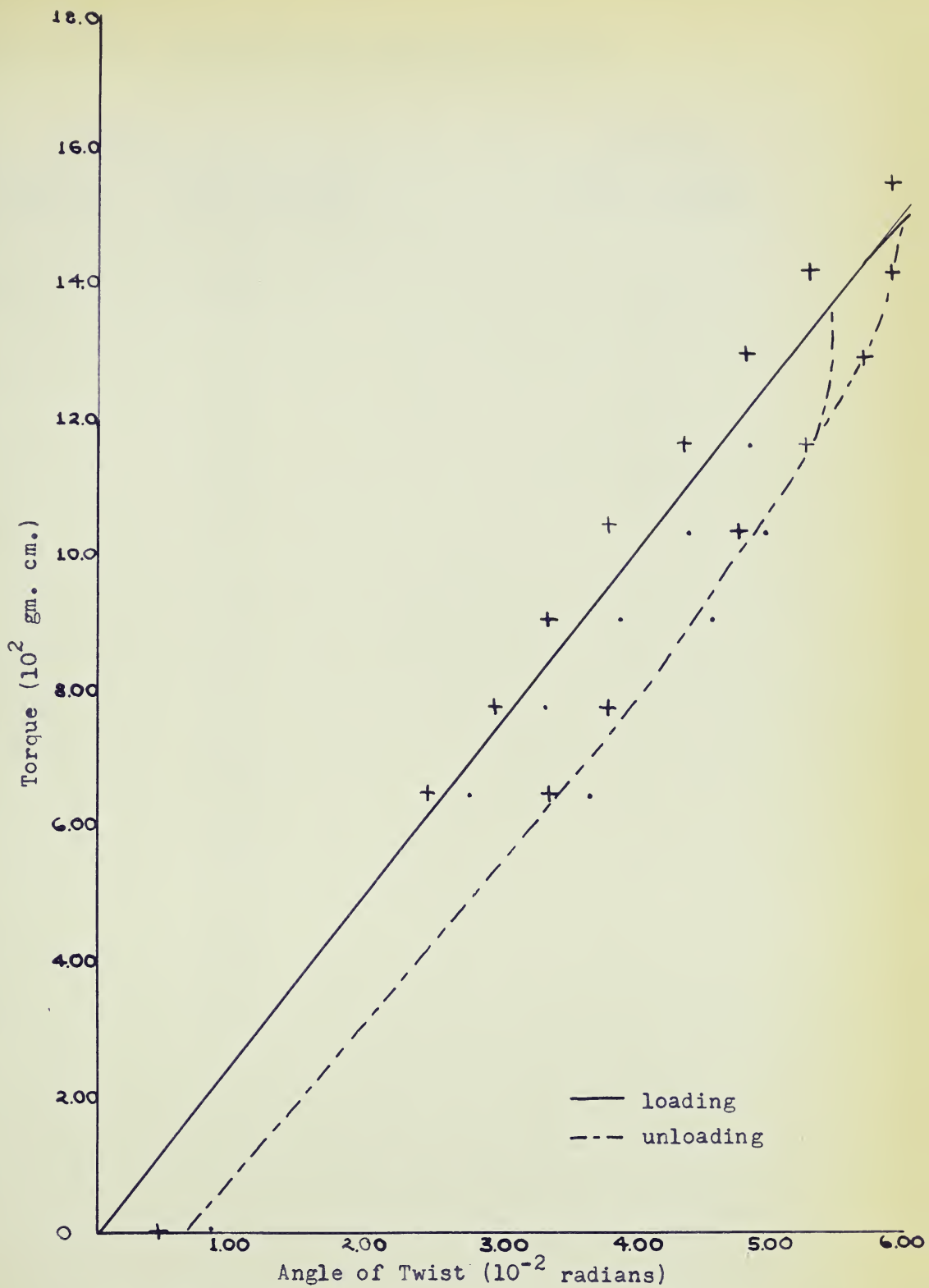


Fig. XXXVII. Copper Crystal Annealed at  $195^{\circ}$  C. at  $23.8^{\circ}$  C.



TABLE XXXVIII. Copper Crystal Annealed at 195°C.  
Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0
6.50	2.19	2.43
7.80	2.60	2.94
9.10	3.25	3.39
10.4	3.67	3.82
11.7	4.19	4.36
13.0	4.85	4.85
0	0	
6.50	2.20	
7.80	2.64	
9.10	3.22	
10.4	3.65	
11.7	4.16	
13.0	4.82	
14.3	5.33	
15.6	5.85	
16.9	6.57	



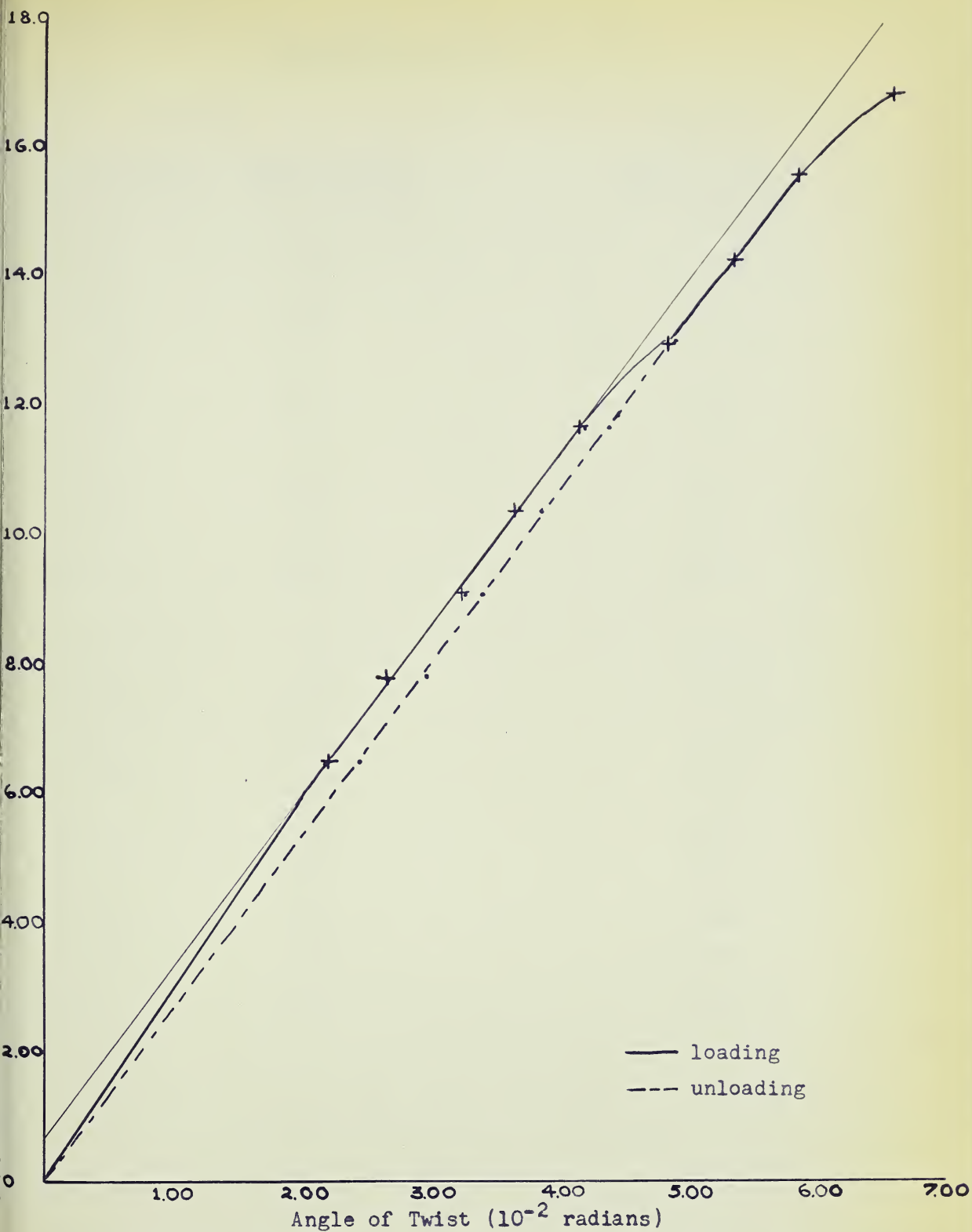


Fig. XXXVIII. Copper Crystal Annealed at  $195^{\circ}$  C.  
Liquid Nitrogen Temperature



TABLE XXXIX. Copper Crystal Annealed at 500°C.  
Temperature 21.6°C.

<u>Loading</u>		<u>Unloading</u>
<u>10<sup>2</sup> Torque</u> <u>gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.355
1.30	0.550	0.785
2.60	1.06	1.36
3.90	1.67	1.91
5.20	2.15	2.45
6.50	2.62	2.91
7.80	3.03	3.44
9.10	3.65	3.92
10.4	4.31	4.31
0	0	0.175
1.30	0.475	0.555
2.60	1.04	1.10
3.90	1.58	1.64
5.20	1.94	2.15
6.50	2.47	2.58
7.80	3.11	2.98
9.10	3.50	3.39
10.4	3.87	3.87



TABLE XXXIX. cont'd. Copper Crystal Annealed at 500°C.  
Temperature 21.6°C.

<u>Loading</u>	
<u>10<sup>2</sup> Torque</u> <u>gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0
1.30	0.300
2.60	0.895
3.90	1.40
5.20	1.84
6.50	2.39
7.80	2.86
9.10	3.31
10.4	3.88
11.7	elastic limit



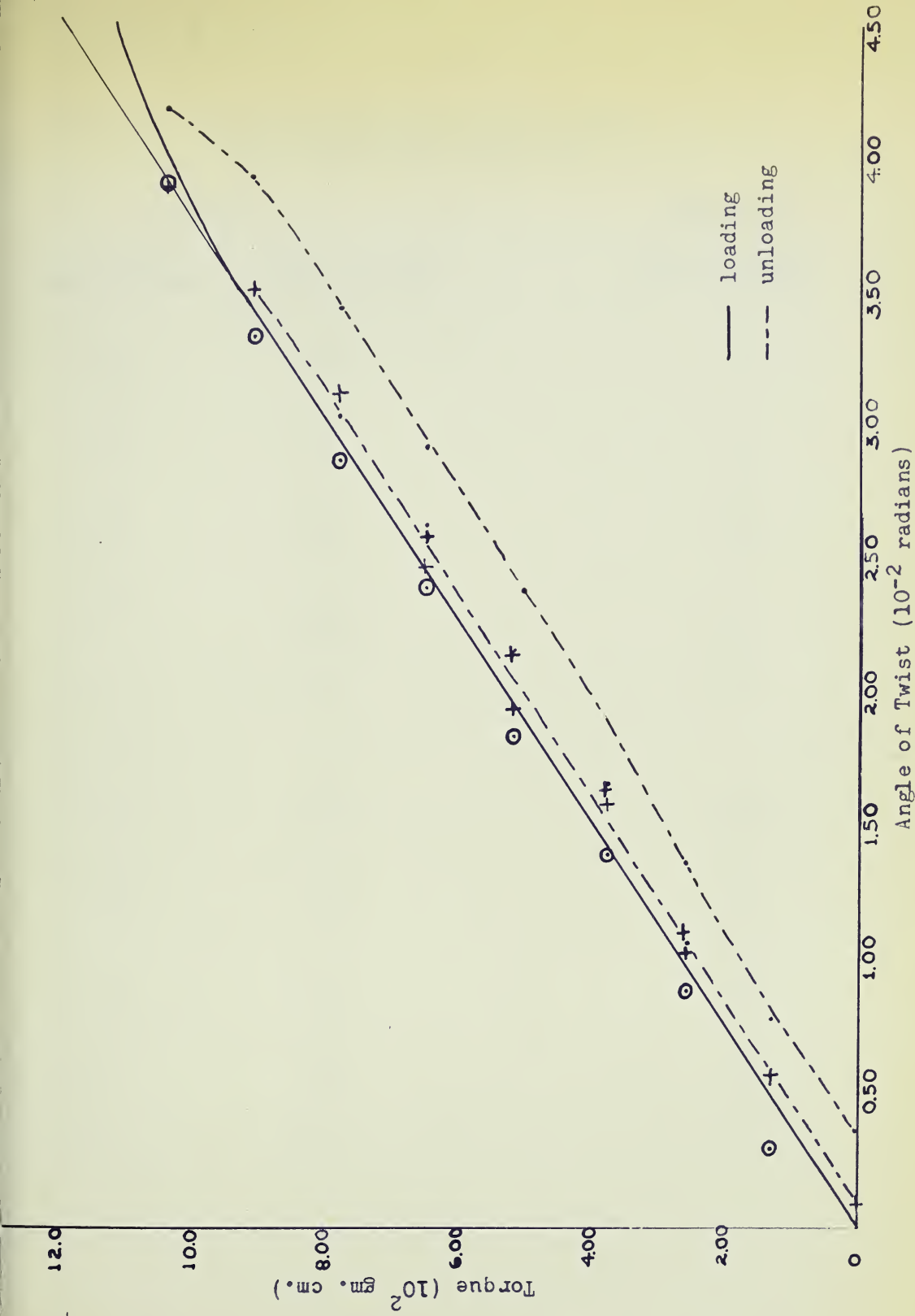


Fig. XXXIX. Copper Crystal Annealed at  $500^{\circ}$  C.  
Temperature  $21.60^{\circ}$  C.



TABLE XL. Copper Crystal Annealed at 500°C.  
Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.22
2.60	0.940	1.26
3.90	1.48	1.73
5.20	1.93	2.24
6.50	2.48	2.81
7.80	2.98	3.28
9.10	3.47	3.81
10.4	3.87	4.32
11.7	4.66	4.66
0	0	0
2.60	0.905	0.995
3.90	1.40	1.40
5.20	1.84	1.90
6.50	2.35	2.46
7.80	2.89	2.95
9.10	3.39	3.45
10.4	3.86	3.95
11.7	4.33	4.33



TABLE XL. cont'd. Copper Crystal Annealed at 500°C.  
Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>
<u><math>10^2</math> Torque gm. cm.</u>	<u>Angle of Twist <math>10^{-2}</math> radians</u>	<u>Angle of Twist <math>10^{-2}</math> radians</u>
0	0	0.11
2.60	0.905	1.10
3.90	1.46	1.56
5.20	1.97	2.05
6.50	2.46	2.61
7.80	2.90	3.13
9.10	3.42	3.65
10.4	3.87	4.10
11.7	4.36	4.36
0	0	
2.60	0.940	
3.90	1.40	
5.20	1.89	
6.50	2.39	
7.80	2.84	
9.10	3.34	
10.4	3.85	
11.7	4.34	
13.0	4.72	
14.3	elastic limit	



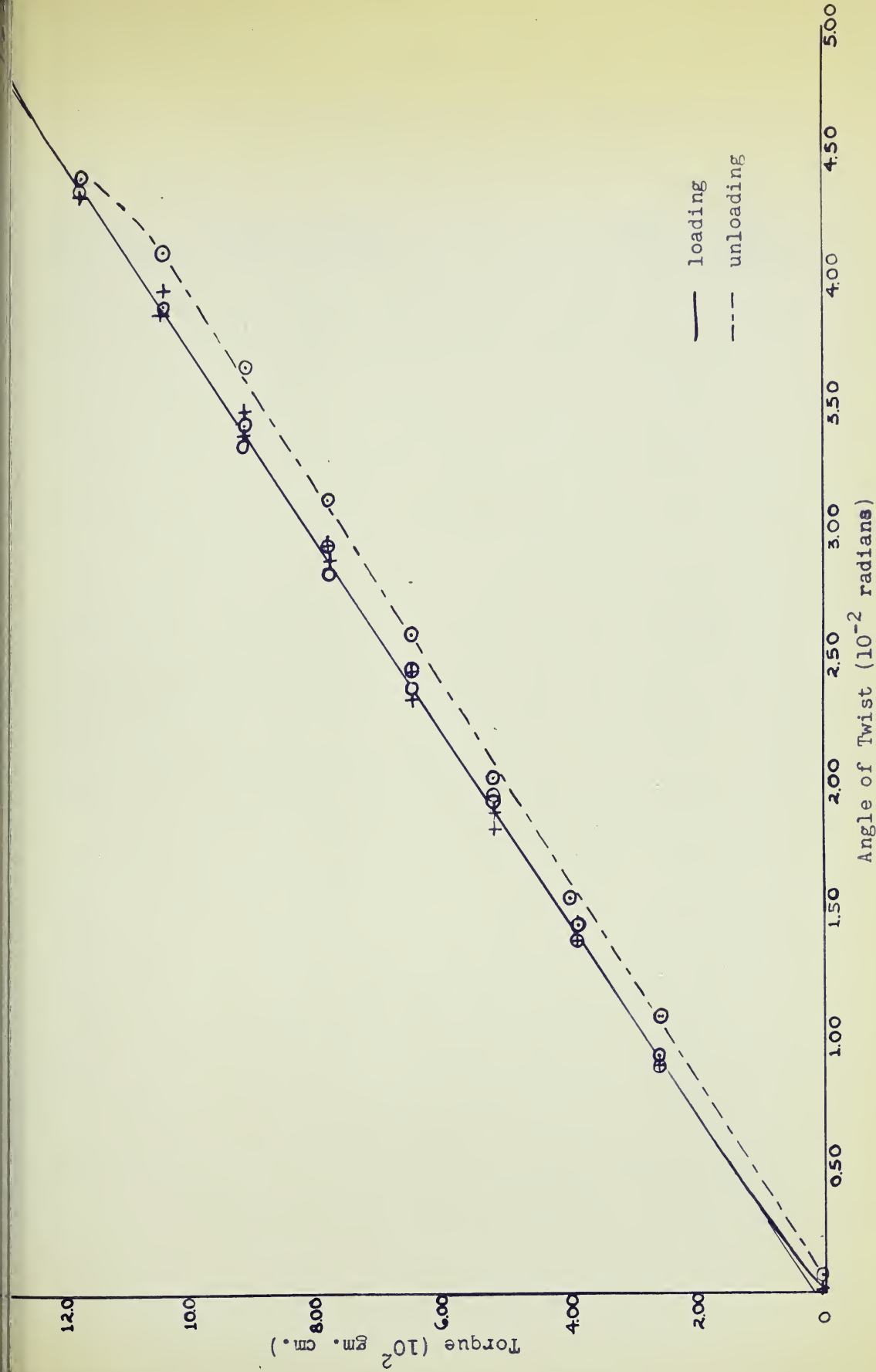


Fig. XL. Copper Crystal Annealed at  $500^{\circ} \text{ C.}$   
Liquid Nitrogen Temperature



TABLE XLI. Aluminum Crystal as Received. Temperature 22.8°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>2</sup> gm.cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.110
2.60	0.585	0.825
5.20	1.22	1.38
6.50	1.52	1.70
7.80	1.83	1.98
9.10	2.12	2.12
0	0	0.055
2.60	0.505	0.760
5.20	1.13	1.27
6.50	1.45	1.61
7.80	1.73	1.87
9.10	1.99	1.99
0	0	0
2.60	0.470	0.710
5.20	1.09	1.25
6.50	1.42	1.55
7.80	1.72	1.81
9.10	2.02	2.02



TABLE XLI. cont'd. Aluminum Crystal as Received.  
Temperature 22.8°C.

Loading

<u>10<sup>2</sup> Torque</u> <u>gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0
2.60	0.490
5.20	1.06
7.80	1.70
9.10	1.96
10.4	2.21
11.7	2.61
13.0	3.80



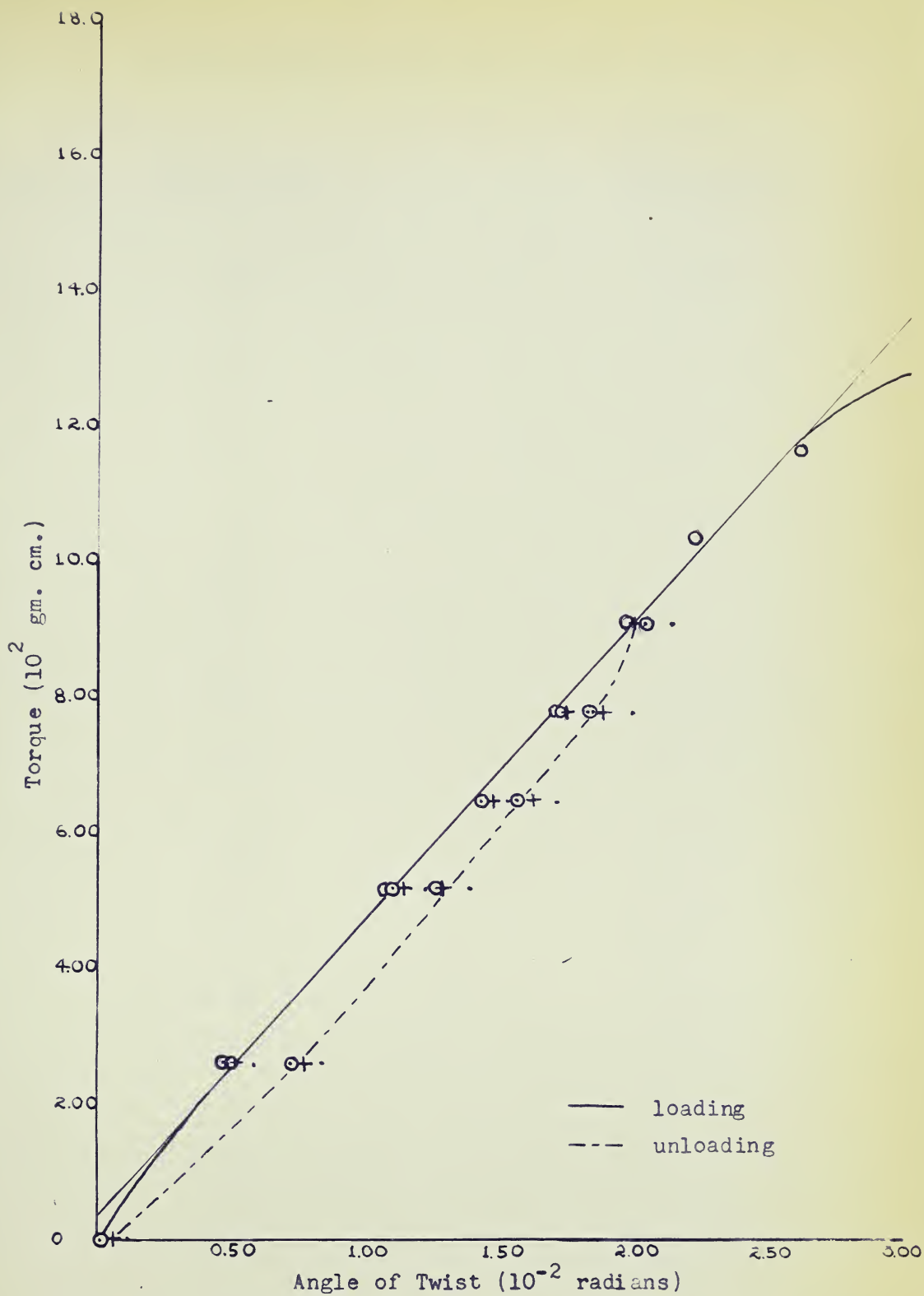


Fig. XLI. Aluminum Crystal as Received.  
Temperature 22.8° C.



TABLE XLII. Aluminum Crystal as Received. Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.065
2.60	0.500	0.665
5.20	1.02	1.22
7.80	1.47	--
10.4	1.94	2.22
13.0	2.57	2.57
0	0	0.040
2.60	0.500	0.600
5.20	1.05	1.18
7.80	1.45	1.65
10.4	1.95	2.15
13.0	2.50	2.50
0	0	0.010
2.60	0.510	0.585
5.20	1.06	1.16
7.80	1.46	1.56
10.4	1.96	2.06
13.0	2.44	2.44
0	0	
5.20	1.05	
10.4	2.00	
13.0	2.60	
14.3	3.15	
15.6	4.25	



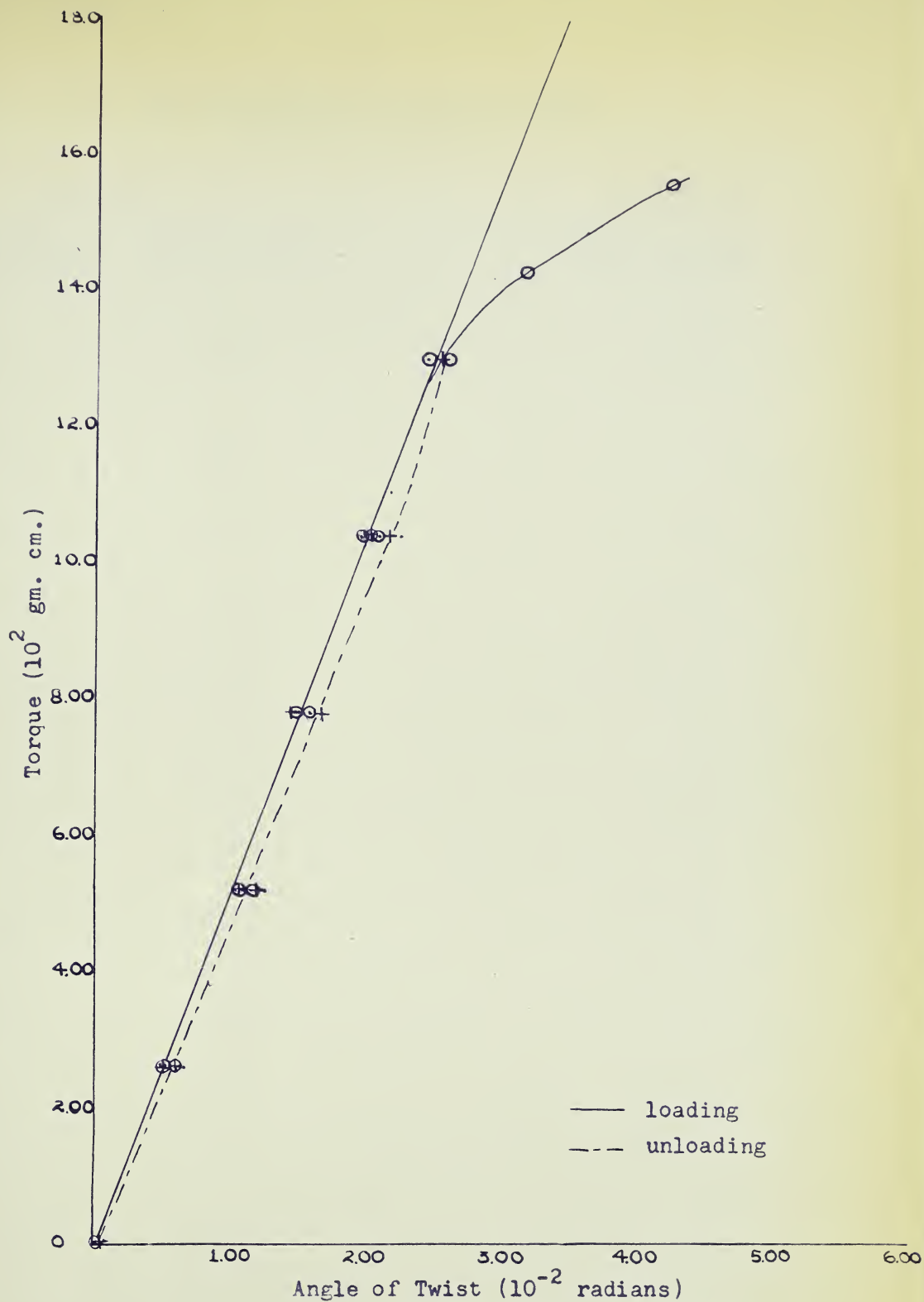


Fig. XLII. Aluminum Crystal as Received.  
Liquid Nitrogen Temperature



TABLE XLIII. Aluminum Crystal Annealed at 200°C.  
Temperature 23.4°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.055
1.30	0.260	0.390
2.60	0.525	0.650
3.90	0.790	0.925
5.20	1.07	1.19
6.50	1.39	1.39
0	0	0.045
1.30	0.255	0.380
2.60	0.530	0.640
3.90	0.800	0.895
5.20	1.08	1.15
6.50	1.40	1.40
0	0	0.230
1.30	0.255	0.505
2.60	0.510	0.795
3.90	0.760	1.06
5.20	1.09	1.35
6.50	1.44	1.44
0	0	
1.30	0.225	
2.60	0.505	
3.90	0.770	
5.20	1.09	
6.50	1.37	
7.80	2.02	



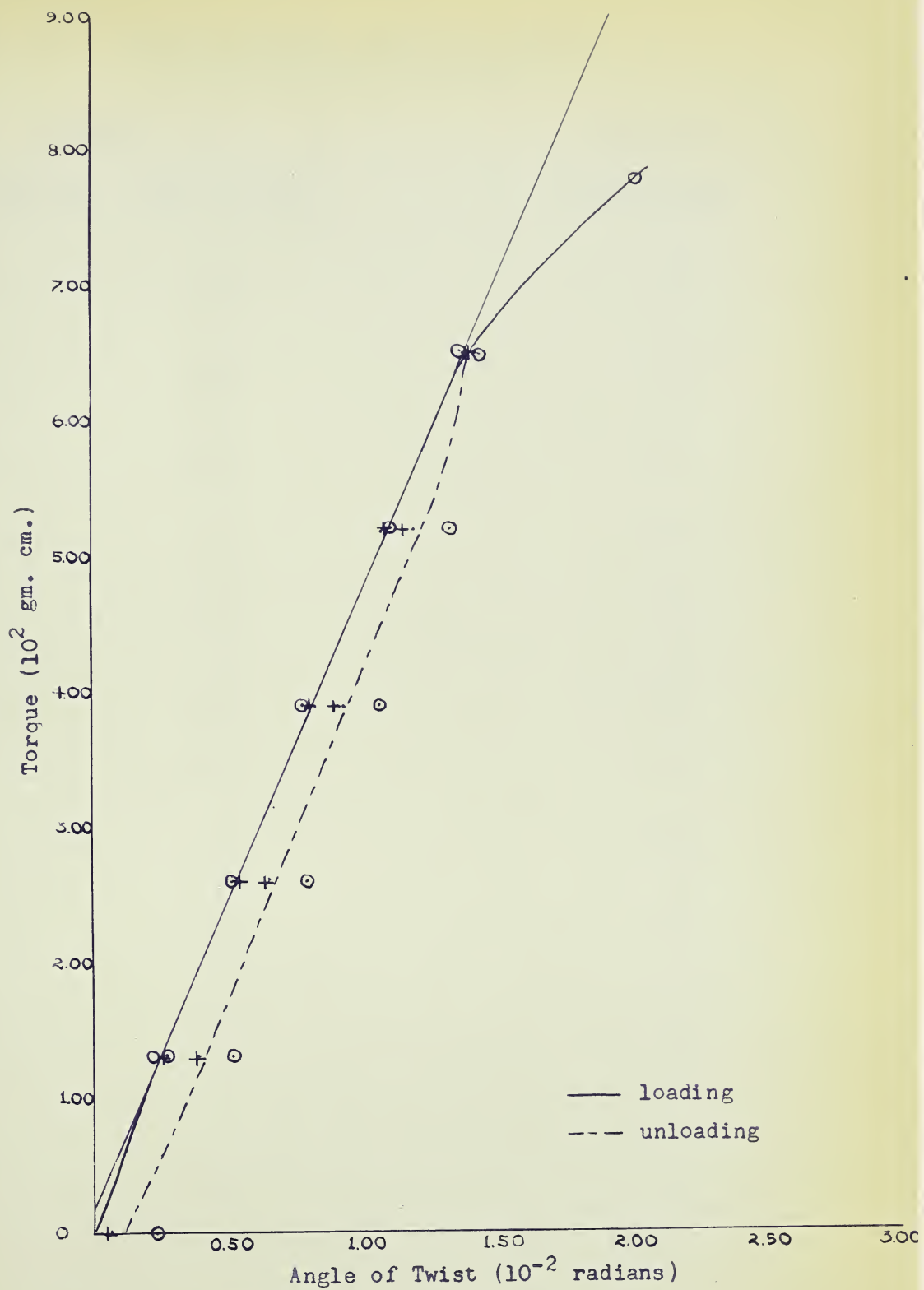


Fig. XLIII. Aluminum Crystal Annealed at  $200^{\circ}$  C.  
Temperature  $23.4^{\circ}$  C.



TABLE XLIV. Aluminum Crystal Annealed at 200°C.  
Liquid Nitrogen Temperature

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.035
1.30	0.275	0.335
2.60	0.545	0.600
3.90	0.790	0.860
5.20	1.03	1.10
6.50	1.30	1.30
0	0	0.005
1.30	0.240	0.305
2.60	0.520	0.555
3.90	0.770	0.810
5.20	1.02	1.06
6.50	1.27	1.27
0	0	0.010
1.30	0.255	0.310
2.60	0.525	0.560
3.90	0.770	0.810
5.20	1.01	1.05
6.50	1.26	1.26



TABLE XLIV. cont'd. Aluminum Crystal Annealed at 200°C.  
Liquid Nitrogen Temperature

<u>Loading</u>	
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0
1.30	0.250
2.60	0.520
3.90	0.755
5.20	1.00
6.50	1.25
7.80	1.54
9.10	2.05



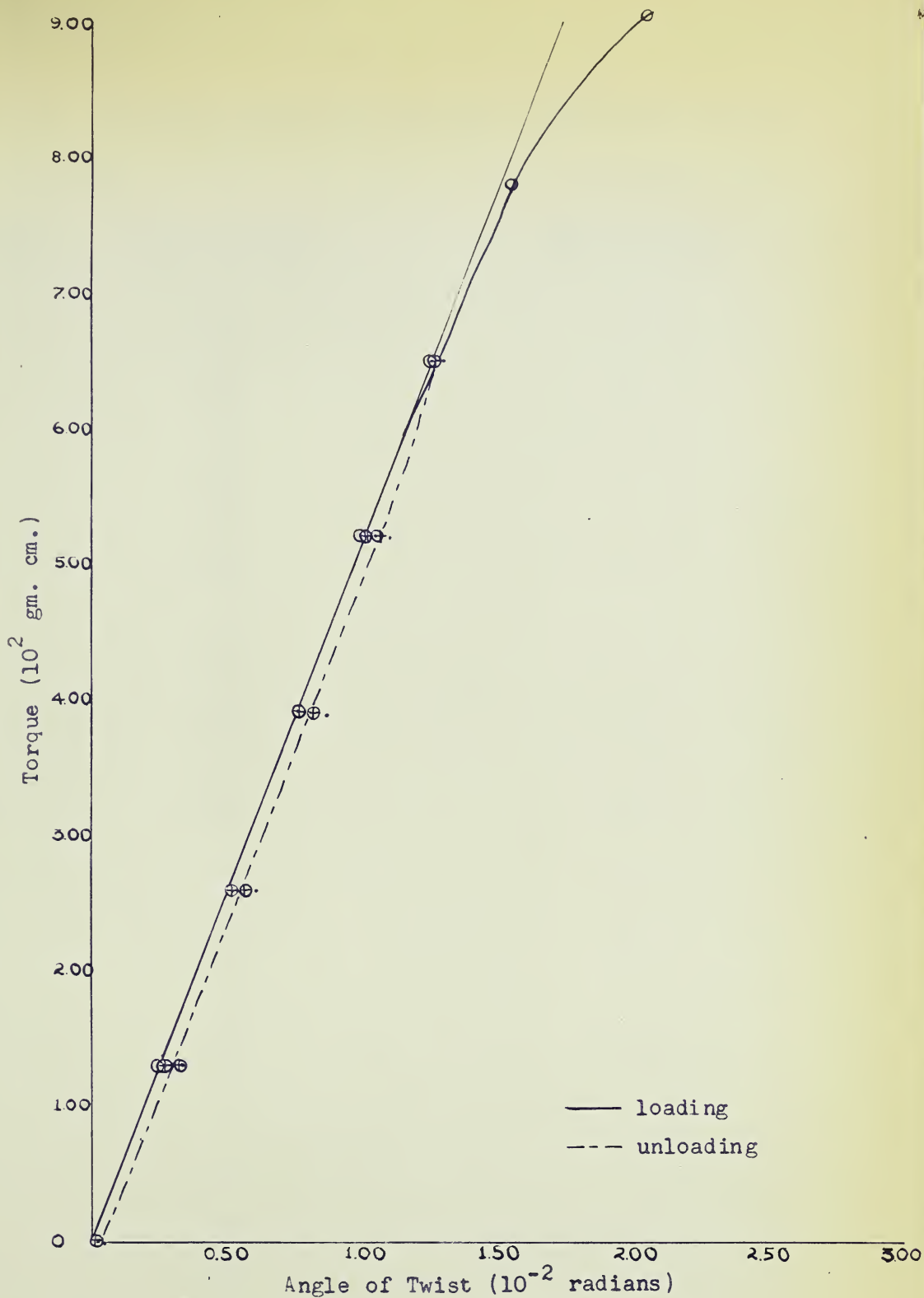


Fig. XLIV. Aluminum Crystal Annealed at 200° C.  
Liquid Nitrogen Temperature



TABLE XLV. Magnesium Crystal as Received. Temperature 24.0°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.49
1.30	0.990	1.88
2.60	2.36	3.14
3.90	3.60	4.45
4.42	4.09	4.90
4.94	4.76	--
5.46	5.46	5.46
0	0	0
2.60	2.21	2.94
3.90	3.68	4.38
5.20	5.15	5.81
6.50	6.56	6.56
0	0	0.15
2.60	2.38	3.20
3.90	3.78	4.65
5.20	5.19	5.85
6.50	6.83	6.83
0	0	
2.60	2.46	
5.20	5.51	
7.80	8.38	
9.10	10.2	
10.4	11.8	
11.7	14.6	



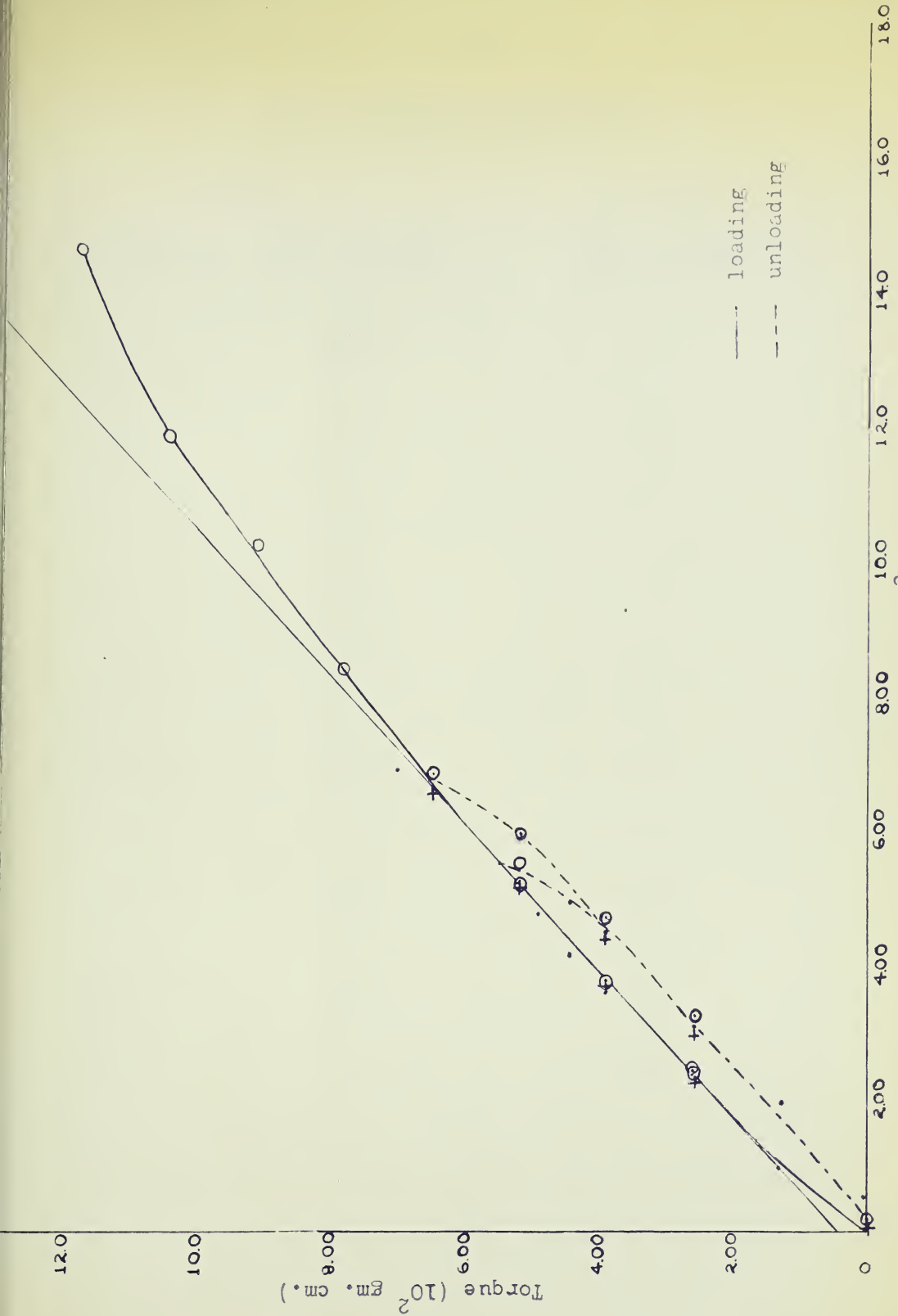


Fig. XLV. Magnesium Crystal as Received.  
Temperature 24.00 C.



TABLE XLVI. Magnesium Crystal as Received.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>
<u><math>10^2</math> Torque gm. cm.</u>	<u>Angle of Twist <math>10^{-2}</math> radians</u>	<u>Angle of Twist <math>10^{-2}</math> radians</u>
0	0	0.300
1.30	1.00	1.40
2.60	2.20	2.75
3.90	3.27	3.76
5.20	4.68	4.68
0	0	0.500
2.60	2.10	2.94
3.90	3.25	4.38
5.20	4.50	5.55
6.50	5.70	6.76
7.80	7.20	7.20
0	0	0.050
2.60	2.05	2.55
3.90	3.35	3.83
5.20	4.56	5.05
6.50	5.70	6.20
7.80	6.95	6.95



TABLE XLVI. cont'd. Magnesium Crystal as Received.  
Liquid Nitrogen Temperature.

<u>Loading</u>	
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0
2.60	2.13
5.20	4.53
7.80	6.92
9.10	8.68
10.4	10.1
11.7	11.4
13.0	13.5



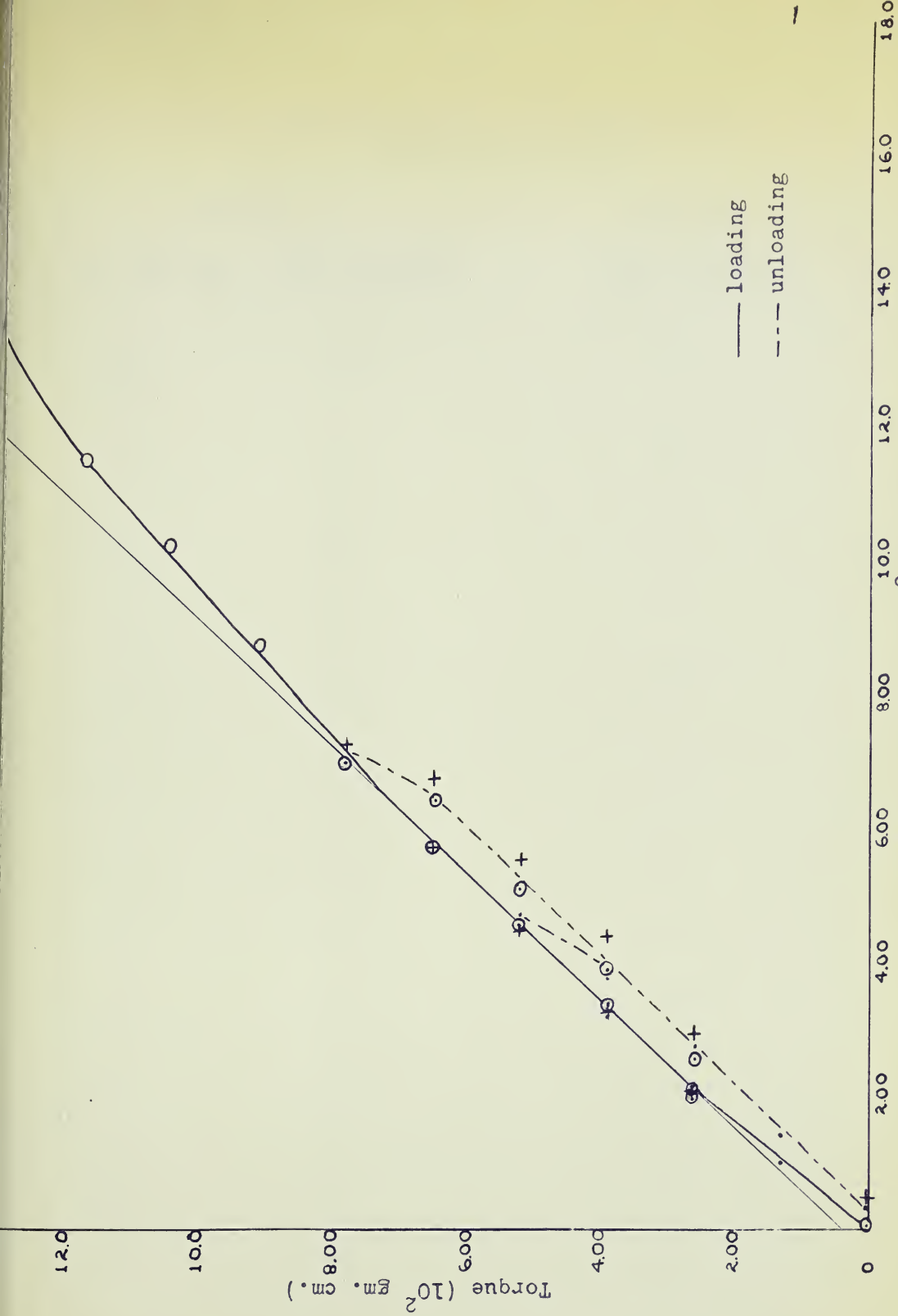


Fig. XLVI. Magnesium Crystal as Received.  
Liquid Nitrogen Temperature.



TABLE XLVII. Magnesium Crystal Annealed at 200°C.  
Temperature 25.5°C.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0.125
1.30	1.09	1.56
2.60	2.30	2.86
3.90	3.45	3.80
4.16	3.65	3.95
4.42	3.85	4.05
4.68	4.10	4.10
0	0	0.095
1.30	1.13	1.52
2.60	2.32	2.79
3.90	3.43	3.77
4.16	3.68	3.92
4.42	3.91	4.07
4.68	4.13	4.13
0	0	0.065
1.30	1.10	1.48
2.60	2.28	2.78
3.90	3.46	3.73
4.16	3.67	3.88
4.42	3.94	3.99
4.68	4.07	4.07



TABLE XLVII. cont'd. Magnesium Crystal Annealed at 200°C.  
Temperature 25.5°C.

<u>Loading</u>	
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0
1.30	1.07
2.60	2.37
3.90	3.46
5.20	4.81
6.50	6.08
7.80	7.30
9.10	10.2



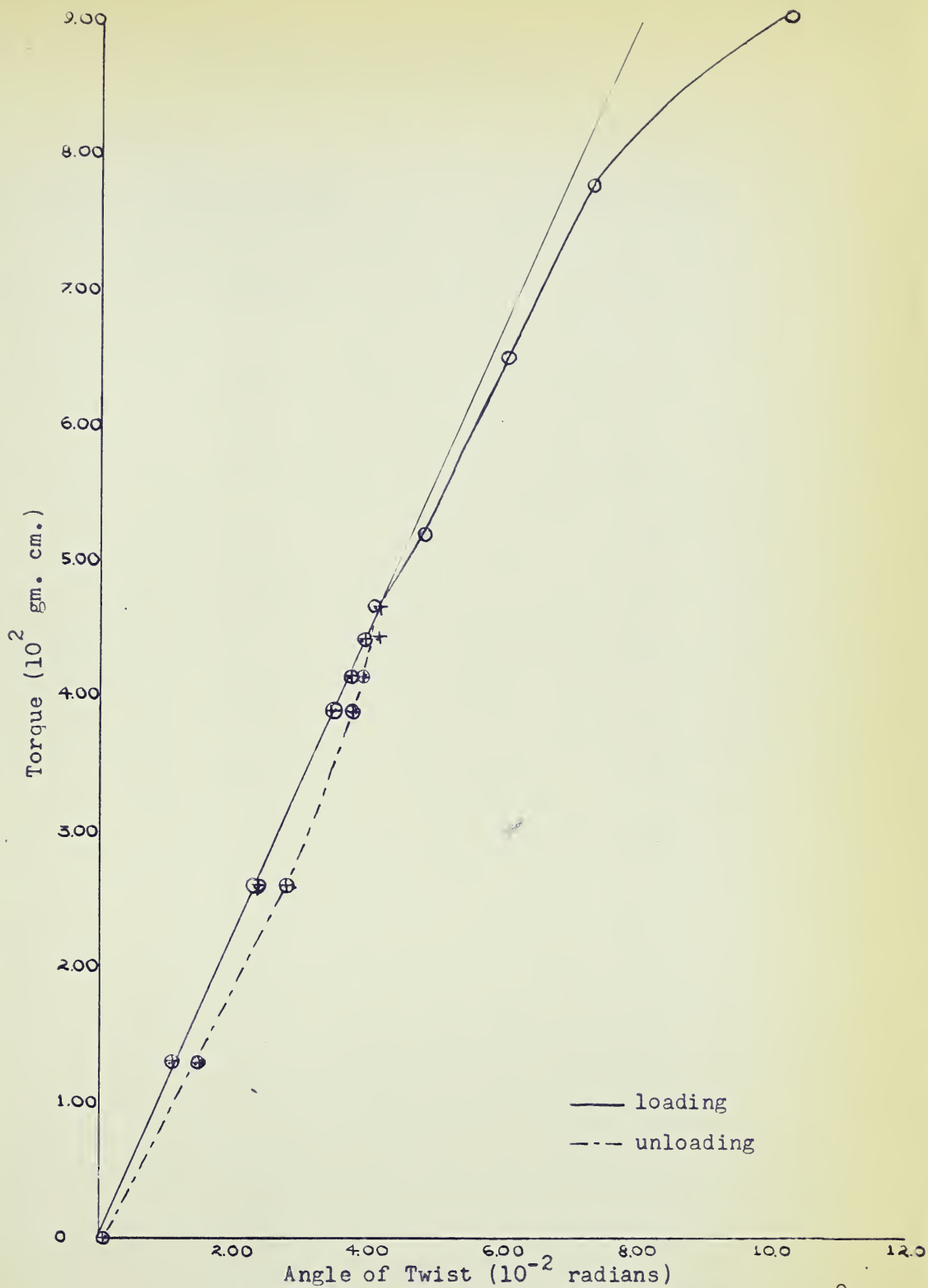


Fig. XLVII. Magnesium Crystal Annealed at 200° C.  
Temperature 25.5° C.



TABLE XLVIII. Magnesium Crystal Annealed at 200°C.  
Liquid Nitrogen Temperature.

<u>Loading</u>		<u>Unloading</u>
<u>Torque</u> <u>10<sup>2</sup> gm. cm.</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>	<u>Angle of Twist</u> <u>10<sup>-2</sup> radians</u>
0	0	0
1.30	0.950	1.16
2.60	2.12	2.42
3.90	3.12	3.42
4.42	3.56	3.85
4.94	4.16	4.16
0	0	0.040
1.30	0.975	1.53
2.60	2.19	2.72
3.90	3.33	3.75
4.42	3.78	4.14
4.94	4.33	4.33
0	0	0.015
1.30	1.07	1.32
2.60	2.17	2.53
3.90	3.32	3.56
4.42	3.72	3.96
4.94	4.25	4.25
0	0	
1.30	1.01	
2.60	2.13	
3.90	3.24	
5.20	4.42	
6.50	5.71	
7.80	7.38	



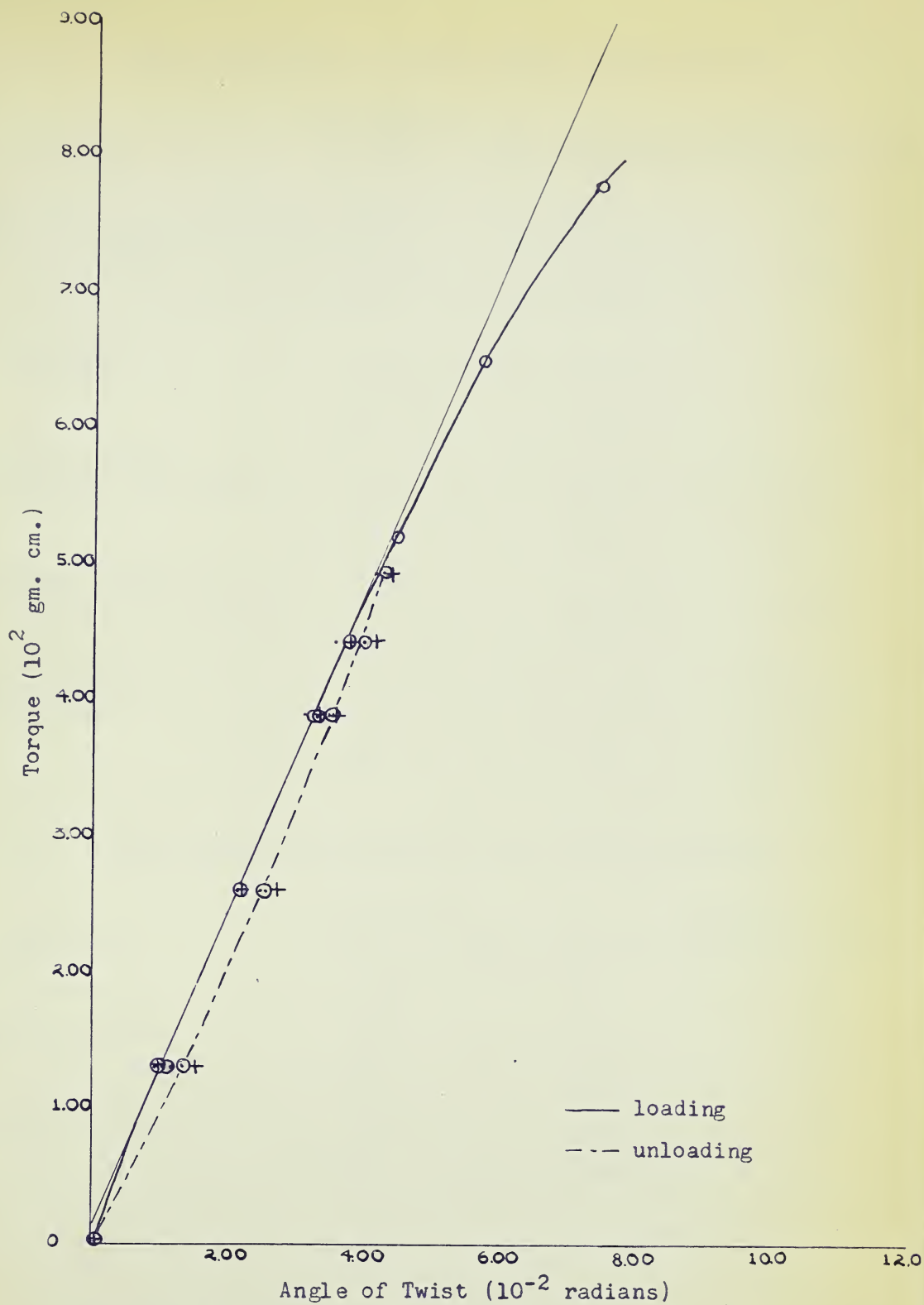


Fig. XLVIII. Magnesium Crystal Annealed at  $200^{\circ}$  C.  
Liquid Nitrogen Temperature



TABLE XLIX. Young's Modulus and Elastic Limit: Brass Crystal

<u>Condition</u>	<u>Temperature °C.</u>	<u>Y (10<sup>11</sup> dynes/cm.<sup>2</sup>)</u>	<u>Elastic Limit (10<sup>8</sup> dynes/cm.<sup>2</sup>)</u>
As Received	24.0	2.13	1.8
Annealed at 500°C.	28.1	3.29	1.3
	-196	2.98	
Heated at 500°C. and Quenched	22.5	2.47	1.4
	-196	2.22	
Annealed at 500°C. and Quenched from 450°C.	22.1	1.76	1.8
	-196	2.06	
Annealed at 500°C. and Quenched from 400°C.	22.4	2.44	1.7
	-196	2.44	
Heated at 575°C. and Quenched	22.4	2.78	2.2
	-196	2.39	

TABLE L. Young's Modulus and Elastic Limit: Copper Crystal

<u>Condition</u>	<u>Temperature °C.</u>	<u>Y (10<sup>11</sup> dynes/cm.<sup>2</sup>)</u>	<u>Elastic Limit (10<sup>8</sup> dynes/cm.<sup>2</sup>)</u>
As Received	27.9	5.27	1.1
Annealed at 195°C.	28.1	5.14	1.1
	-196	5.28	1.3
Annealed at 500°C.	21.1	6.24	1.7
	-196	6.08	



TABLE LI. Young's Modulus and Elastic Limit: Zinc Crystal

<u>Condition</u>	<u>Temperature °C</u>	<u>Y (10<sup>11</sup> dynes/cm.<sup>2</sup>)</u>	<u>Elastic Limit (10<sup>8</sup> dynes/cm.<sup>2</sup>)</u>
As Received	28.1	7.87	1.5
Annealed at 100°C.	25.0	4.29	1.4
	-196	4.45	1.7(breaking point)

TABLE LII. Young's Modulus and Elastic Limit: Magnesium Crystal

<u>Condition</u>	<u>Temperature °C</u>	<u>Y (10<sup>11</sup> dynes/cm.<sup>2</sup>)</u>	<u>Elastic Limit (10<sup>8</sup> dynes/cm.<sup>2</sup>)</u>
As Received	21.6	2.20	1.2
	-196	2.53	1.4
Annealed at 200°C.	25.0	2.17	0.84
	-196	2.54	1.1

TABLE LIII. Young's Modulus and Elastic Limit: Aluminum Crystal

<u>Condition</u>	<u>Temperature °C</u>	<u>Y (10<sup>11</sup> dynes/cm.<sup>2</sup>)</u>	<u>Elastic Limit (10<sup>8</sup> dynes/cm.<sup>2</sup>)</u>
As Received	21.8	1.72	6.7
	-196	2.68	9.0
Annealed at 200°C.	22.5	2.02	5.9
	-196	2.82	6.8



TABLE LIV. Torsion Modulus and Elastic Limit: Brass Crystal

<u>Condition</u>	<u>Temperature °C.</u>	<u><math>10^{11}</math> n dynes/cm.<sup>2</sup></u>	<u>Critical Stress (<math>10^8</math> dynes/cm.<sup>2</sup>)</u>
Annealed at 500° C.	25.4	4.11	3.8
	-196	4.63	9.9
Heated at 500° C. and Quenched	-196	4.22	7.7
Annealed at 500° C. and Quenched from 450° C.	22.0	3.87	5.2
	-196	3.94	8.4
Annealed at 500° C. and Quenched from 400° C.	22.8	3.98	6.1
	-196	4.12	9.6
Heated at 575° C. and Quenched	22.4	4.02	5.0
	-196	4.06	7.5

TABLE LV. Torsion Modulus and Elastic Limit: Copper Crystal

<u>Condition</u>	<u>Temperature °C.</u>	<u><math>10^{11}</math> n dynes/cm.<sup>2</sup></u>	<u>Critical Stress (<math>10^8</math> dynes/cm.<sup>2</sup>)</u>
Annealed at 195° C.	23.8	3.21	3.4
	-196	3.40	3.6
Annealed at 500° C.	22.6	3.40	2.6
	-196	3.37	3.2



TABLE LVI. Torsion Modulus and Elastic Limit: Magnesium Crystal

<u>Condition</u>	<u>Temperature °C</u>	<u>n (10<sup>11</sup> dynes/cm.<sup>2</sup>)</u>	<u>Critical Stress (10<sup>8</sup> dynes/cm.<sup>2</sup>)</u>
As Received	24.0	1.29	1.2
	-196	1.50	1.5
Annealed at 200° C.	25.5	1.59	0.98
	-196	1.84	1.1

TABLE LVII. Torsion Modulus and Elastic Limit: Aluminum Crystal

<u>Condition</u>	<u>Temperature °C</u>	<u>n (10<sup>11</sup> dynes/cm.<sup>2</sup>)</u>	<u>Critical Stress (10<sup>8</sup> dynes/cm.<sup>2</sup>)</u>
As Received	22.8	2.22	1.0
	-196	2.33	1.0
Annealed at 200° C.	23.4	2.31	0.57
	-196	2.63	0.57



TABLE LVIII.

Effect of Heat Treatment and Low Temperature on Young's Modulus (Y) and Elastic Limit

	Brass	Copper	Zinc	Aluminum	Magnesium
Heat Treatment	Increase in Y for all but one state. Low value of Y after quenching from 450°C. Elastic limit higher after quenching from 575°C.	Increase in Y after annealing at 500°C. Elastic limit higher after annealing at 500°C. Very little effect after annealing at 195°C.	Large decrease in Y after annealing at 100°C. Small change in elastic limit (a little lower) after annealing at 100°C.	Increase in Y and elastic limit lower after annealing at 200°C.	No appreciable effect in Y after annealing at 200°C. Elastic limit lower after annealing at 200°C.
Low Temperature	Decrease in Y for all but one state. Increase in Y after quenching from 450°C. Elastic limit higher.	Increase in Y for all but one state. Decrease in Y after annealing at 500°C. Elastic limit higher.	Increase in Y. Elastic limit higher. Became brittle after annealing.	Increase in Y. Elastic limit higher.	Increase in Y. Elastic limit higher.



TABLE LIX.

Effect of Heat Treatment and Low Temperature on Torsion Modulus (n) and Elastic Limit

	Brass	Copper	Zinc	Aluminum	Magnesium
Heat Treatment	Small effect on n. Smaller value for n after quenching. Lowest value of n after quenching from 450°C.	No appreciable change in n. Elastic limit smaller after annealing at 500°C.	n very small at all temperatures	n increased and elastic limit greatly decreased after annealing at 200°C.	n increased and elastic limit decreased after annealing at 200°C.
Low Temperature	Slight increase in n. Elastic limit much higher	Small increase in n, except after annealing at 500°C. Decreased after annealing at 500°C. Elastic limit higher.		n higher. Elastic limit unchanged.	n higher. Elastic limit higher.



## V DISCUSSION OF RESULTS

The results obtained in the experiment give us a concept of the effect of heat treatment and low temperature upon the elastic moduli and elastic limits of the single crystals investigated. The Young's modulus and torsion modulus values of all the crystals, with the exception of the torsion modulus value for zinc, were given in spite of some evidence of plasticity.

The results with quenched beta-brass show that the temperature anomaly of the Young's modulus exists at lower temperatures when the crystal possesses frozen-in disorder as well as when it is in the equilibrium ordered state. This is inconsistent with Zener's explanation of the change in sign of the temperature coefficient of  $\frac{1}{2}(C_{11}-C_{12})$ , as mentioned in the theory.

I suggest that the decrease in Young's modulus with decrease in temperature for the  $\{100\}$  and  $\{110\}$  directions of the beta-brass is caused by an increased concentration of flaws along with a possible increase in disorder. Gorsky (1935) has pointed out that a change in the lattice dimensions by an externally applied stress changes the equilibrium order. On account of the long time delay associated with the establishment of equilibrium at low temperatures, the stretched crystal is not in the proper equilibrium state, so that there may be an increased concentration of vacancies or flaws, giving rise to the observed anisotropic effects. Experience has shown that the disorder of the lattice and the density of vacancies or flaws increases with increasing cold work. Although the amount of cold work is small in taking a crystal through a complete cycle, it would cause some increase in the number of flaws and in the disorder. The atoms in the  $\{100\}$  and  $\{110\}$  directions are more loosely packed than in the  $\{111\}$  direction. It would therefore seem reasonable to assume



that the number of generated flaws and the amount of disorder would be greater along these directions. Since an increase in the number of vacancies or flaws weakens the crystal the decrease in the Young's modulus would be greater along these directions. This suggestion does not contradict Taylor's theory of the motion of dislocations which causes slip as outlined in Chapter II, since it has been shown by previous investigators that slip caused by the motion of dislocations in beta-brass single crystals takes place in the  $[111]$  direction at lower temperatures.

The results also show that the Young's modulus is much lower when the crystal is in the disordered state at both room and liquid nitrogen temperatures. This adds support to the suggestion that the decrease in the Young's modulus in the  $[100]$  and  $[110]$  direction of beta-brass with decrease in temperature is due to the fact that the stretched crystal is farther from its equilibrium state of order at lower temperatures. Although the beta-brass crystal was not stretched to the elastic limit at liquid nitrogen temperature, a fairly large hysteresis effect was observed. This would indicate an increase in the number of flaws since it has been shown by Webb (1939) that if the elastic limit is not exceeded at room temperature for beta-brass single crystals the stress-strain relation is linear with no permanent set or hysteresis.

The Young's modulus temperature anomaly which occurs in beta-brass also appeared, but to a smaller degree, in both the Young's and torsion moduli of the copper crystal after it was annealed at  $500^{\circ}\text{C}$ . The only reason that I can suggest for such behaviour is that vacancies or flaws were generated more easily by decrease in temperature while under stress after the crystal was annealed, as it was observed that the crystal became much less pliable after the annealing process.



The Young's modulus for the beta-brass was much smaller and increased with decrease in temperature after heating the crystal to  $500^{\circ}\text{C}$  and quenching it from  $450^{\circ}\text{C}$ . It is difficult to explain this observation. Since the crystal was quenched from a temperature in the vicinity of the transition temperature it is possible that the final state was a mixed crystal, consisting partly of ordered regions, which would perhaps cause the above-mentioned effect.

The elastic limit point for elongation of the beta-brass crystal was not reached at liquid nitrogen temperature because of the danger of fracturing the crystal. However, it was clearly shown that the elastic limit at liquid nitrogen temperature was much higher than at room temperature. In fact, the effect of low temperature on the elastic limit of beta-brass was much greater than the effect on the elastic limit of any of the other crystals.

The elastic limits of all the crystals increased considerably at low temperatures with the exception of the torsion elastic limit of aluminum which did not show any change. It is possible that there was an increase in this elastic limit as well, but too small to observe with the apparatus employed.

The graphs of load versus distortion nearly all showed a hysteresis effect on unloading. A hysteresis effect is quite common in most single crystals because some plastic slip occurs throughout the crystal distortion. The test with steel (p. 15) showed that a small difference between loading and unloading may be due to the mercury in the glass tube, but this cannot account for the comparatively large effect often observed. In many cases, especially the trials at room temperatures, this may have been caused by exceeding the elastic limit to too great a degree, and therefore cannot be attributed entirely to plastic slip.

No results were obtained for the torsion modulus of the zinc crystal. The crystal became much weaker and very brittle after annealing. It broke under a tension of  $1.7 \times 10^8$  dynes/cm.<sup>2</sup> at liquid nitrogen temperature in the process of loading for the Young's modulus test. The break was abrupt and along well marked cleavage planes. The behaviour



of single zinc crystals after annealing is therefore similar to polycrystalline zinc. Ewing (1900) showed that after polycrystalline zinc is exposed to  $200^{\circ}\text{C}$  for half an hour, it shows on etching a large brilliant structure, becomes weak and brittle, and breaks along well marked cleavage planes. An attempt was made to use the remaining portion of the crystal in the torsion modulus part of the experiment, but it was found to be very weak and twisted through large angles under very small applied torques.

The values obtained for the elastic moduli and the elastic limits of the crystals in the non-annealed state are in fair agreement with the results of other workers for the crystals which have been previously investigated. The values of the elastic limits at room temperature are somewhat higher than found by some investigators. Extreme accuracy was not contemplated in this experiment, as the prime purpose of the work was to investigate the effects of various heat treatments and low temperature upon the elastic properties of the crystals, and not to establish accurate values for the elastic moduli and elastic limits.

A further experiment similar to the one performed using a number of crystals of one metal and perhaps more refined equipment would appear worth while. This would be especially true for beta-brass because of the Young's modulus temperature anomaly, and for magnesium because it was not definitely established that the sample used in this experiment was a single crystal.



BIBLIOGRAPHY

- Artman, R. A. and Thompson, D. O. 1951. Journal of Applied Physics 22: 358.
- 1952. Journal of Applied Physics 23: 470.
- Artman, R. A. 1952. Journal of Applied Physics 23: 475.
- Bakarian, P. W. and Mathewson, C. H. 1943. Transactions of American Institute of Mining and Metallurgical Engineers 152: 226.
- Bridgman, P. W. 1935. Physical Review 47: 393.
- Cahn, R. W. 1949-50. Institute of Metals Journal 76: 121.
- 1951. Institute of Metals Journal 79: 129.
- Elam, C. F. 1926. Royal Society of London Proceedings, A, 112: 289.
- 1936. Royal Society of London Proceedings, A, 153: 273.
- Ewing, J. A. 1900. Royal Society of London Proceedings, A, 67: 112.
- French, R. S. 1951. Journal of Applied Physics 22: 105.
- Gaffney, J. and Overton, W. C. 1954. Bulletin of the American Physical Society 29: 14.
- Göler, V. and Sachs, G. 1929. Zeitschrift fur Physik 55: 581.
- Good, W. A. 1941. Physical Review 60: 605.
- Gorsky, W. S. 1935. Soviet Physical Journal 8: 562.
- Gough, H. J., Hanson, D. and Wright, S. J. 1926. Philosophical Transactions of the Royal Society, A, 226: 1.
- Gough, H. J. and Cox, H. L. 1929. Royal Society of London Proceedings, A, 123: 143.
- 1930. Royal Society of London Proceedings, A, 127: 453.
- Hanson, A. W. 1934. Physical Review 45: 324.
- Heidenreich, R. D. and Shockley, W. 1948. "Report on a Conference on the Strength of Solids," University of Bristol, England, Physical Society, London.
- Karnop, R. and Sachs, G. 1927. Zeitschrift fur Physik 41: 116.
- Kê, T'ing-Sui. 1949. Physical Review 76: 579.
- Lazarus, D. 1948. Physical Review 74: 1726.



- Neurath, P. W. and Koehler, J. S. 1951. Journal of Applied Physics 22: 621.
- Nowick, A. S. 1950. Physical Review 80: 249.
- Rinehart, J. S. 1940. Physical Review 58: 365.
- \_\_\_\_\_ 1941. Physical Review 59: 308.
- Schmid, E. 1931. Zeitschrift fur Elektrochemie 37: 447.
- Taylor, G. I. and Elam, C. F. 1923. Royal Society of London Proceedings, A, 102: 643.
- Taylor, G. I. 1928. Royal Society of London Proceedings, A, 118: 1.
- \_\_\_\_\_ 1934. Royal Society of London Proceedings, A, 145: 362.
- Tyndall, E. P. T. 1935. Physical Review 47: 398.
- Webb, W. 1939. Physical Review 55: 297.
- Wert, C. A. and Tyndall, E. P. T. 1949. Journal of Applied Physics 20: 587.
- Yamaguchi, K. 1928. Scientific Papers, Institute of Physical and Chemical Research (Tokyo) 8: 289.
- Yamashita, T. 1953. Journal of Science, Hiroshima University, A, 17: 245.
- Zener, C. 1947. Physical Review 71: 846.



# APPENDIX

## Identification of a Crystal Axis from a Laue Photograph

Consider an X-ray beam incident upon a crystal at O with one of the principal crystal planes inclined at an angle  $\theta$  to the beam (fig. i, a). Reflection will give rise to a spot A on the photographic plate. Extension of the plane OF to intersect the photographic plate at C will give

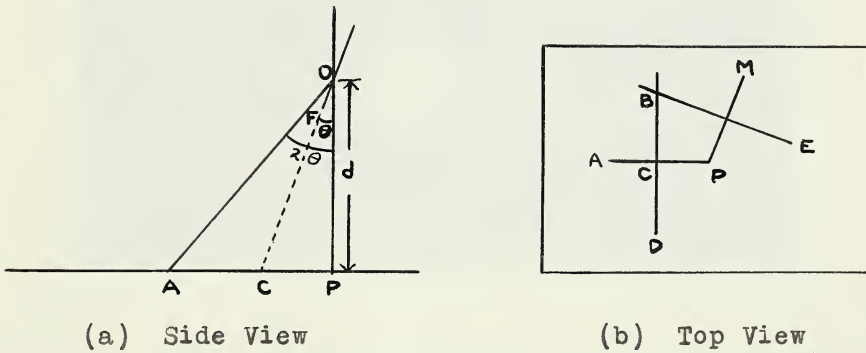


Fig. i. Identification of a Crystal Axis from a Laue Photograph

rise to a line BCD (fig. i, b) making a right angle with ACP.  $PA = d \tan 2\theta$  where  $d$  is the distance from the crystal to the photographic plate. CP can be readily calculated. If angle  $\theta$  is small  $CP = \frac{1}{2} PA$ .

If the intersections of two principal planes with the plane of the photographic plate are plotted, the junction of the two lines so obtained marks a point on the crystal axis (Point B; fig. i, b). From the measurement of the position of this point the angle of tilt of the crystal axis with the X-ray beam or axis of cylindrical sample can be



readily determined, as well as the horizontal angle between the plane of tilt and a vertical principal plane of the crystal.

The X-ray photograph of the beta-brass single crystal is shown in fig. ii. An enlarged plot of the X-ray photo-



Fig. ii. Laue Photograph of Beta-Brass Single Crystal

graph illustrating the angle of tilt of the crystal axis with the axis of the sample and the assumed (100) plane of the crystal is shown in fig. iii. The angle that the crystal axis makes with the axis of the sample is obtained from  $\tan \phi = \frac{O_o}{d}$ . The enlarged plot was made three times the size of the original photograph. The distance  $d$  equaled 5.0 cm. for the beta-brass X-ray photograph. The distance  $O_o$  from fig. iii was measured as 1.45 cm.. Therefore  $\tan \phi = \frac{1.45}{3 \times 5} = 0.0967$  and  $\phi = 5.5^\circ$ . The angle the crystal axis made with the assumed (100) plane of the crystal was read directly from fig. iii. It is the angle between the broken line  $O_oX$  and the line representing the assumed (100) plane, and equals  $7.0^\circ$ .



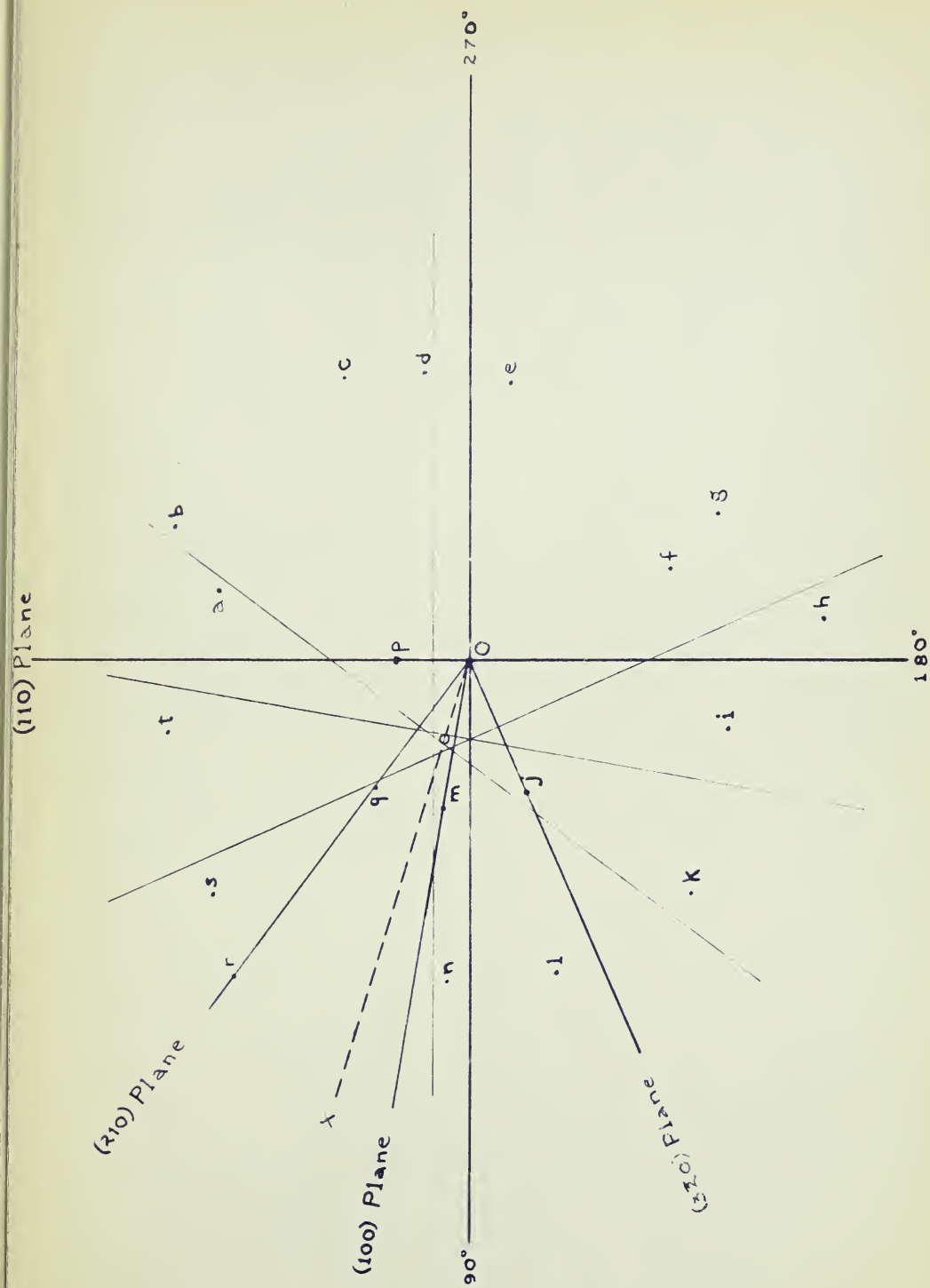


Fig. iii. Determination of Angle of Tilt of Crystal Axis





**B29774**